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OIL AND RETORTABLE MATERIALS

A HANDBOOK

ON

THE UTILISATION OF COAL,
TORBANITE, CANNEL AND OIL SHALE.

BY

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With Two Plates.



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1927.

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P R E F A C E.

THE world's future supplies of liquid fuel seem to afford scope for the most divergent opinions. American experts have prophesied that the available petroleum in that country would be practically exhausted in less than 30 years ; other experts consider that the oil companies can furnish adequate supplies for generations. It is, however, in countries which have no indigenous oil that the subject is least understood, and where in consequence exaggerated and biased statements may do most harm. In Britain we are told, on the one hand, that by properly utilising our coal and allied materials we could supply most of our liquid fuel requirements from home resources ; on the other hand, it is said that this is an economic impossibility.

Such diverse opinions, all equally authoritative, must be perplexing to the large company of people who to-day are interested one way or another in this subject, but who are unfamiliar with its technical details and therefore find difficulty in forming a judgment upon matters calling for their decision.

The author of this little book has endeavoured to meet this need by briefly describing in outline

the essentials of the various processes for obtaining liquid fuels, and relying upon his experience he has co-ordinated and correlated the many different procedures by which liquid fuel is procured so that they may be seen in true perspective to one another as well as to liquid fuel in general. The published results of other research workers and papers read before scientific Societies, as well as contributions to the technical press have been carefully considered, and when quoted, the source has been gratefully acknowledged.

The importance of liquid fuel to National life cannot be over-estimated and a right understanding of what has been accomplished towards making additional supplies available is of great moment, therefore the author hopes this discussion of the subject may prove useful.

G. W. HALSE.

LONDON, *March*, 1927.

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OIL AND RETORTABLE MATERIALS.

CHAPTER I.

FUEL.

THE discovery by primeval savages of the use of fire in rendering their enemies and other food more palatable and digestible must have been the epoch-making event of those far-off days. During the last two or three centuries, fuel has been the dominant factor rendering possible the phenomenal advances of civilisation, and in fact its use has been in a great measure responsible for the making of the present great nations of the earth. To-day, not only are fuel supplies of far greater importance than ever, but they are likely to continue to increase in importance until the time when other sources of energy, such as solar heat, tidal effort, intra-atomic energy, etc., may be made available by science. In the meantime the state of advancement of any nation may be to a great extent judged by its *power output* (mostly derived from fuel) per head of population. It follows,

therefore, that those nations which have the largest and cheapest resources of fuel, which is at present synonymous with large and cheap resources of power for industry, will be the best able to compete in the world's markets, and their success will depend in no small measure on the degree of efficiency with which they utilise their raw fuels. In this connection it is the opinion of many who have made a study of the fuel problem in Great Britain, that the prosperity of the country is inexorably linked up with the means by which use is made of the bountiful supplies of coal which the country possesses, and that there is an enormous amount of leeway to be made up in the modernising of plant or the installation of new plant for the generation and distribution of power, before it can be said that anything approaching adequate advantage is being taken of the fuels available.

Fig. 1 shows, on different scales, the *world's coal* and *petroleum* production since 1895. The decrease in coal and the extraordinary increase in oil since 1913 strikingly brings out the rapidly rising importance of oil as a world source of power. The manner in which oil is replacing coal is shown clearly in Fig. 2, in which the world's oil production is plotted as the percentage of the world's coal production for each year. It seems certain that, on account of economic conditions,

the rapid rise in this curve during the last few years cannot be maintained: even if the oil be reasonably available, the cost of again doubling the output in a five-year period, as happened

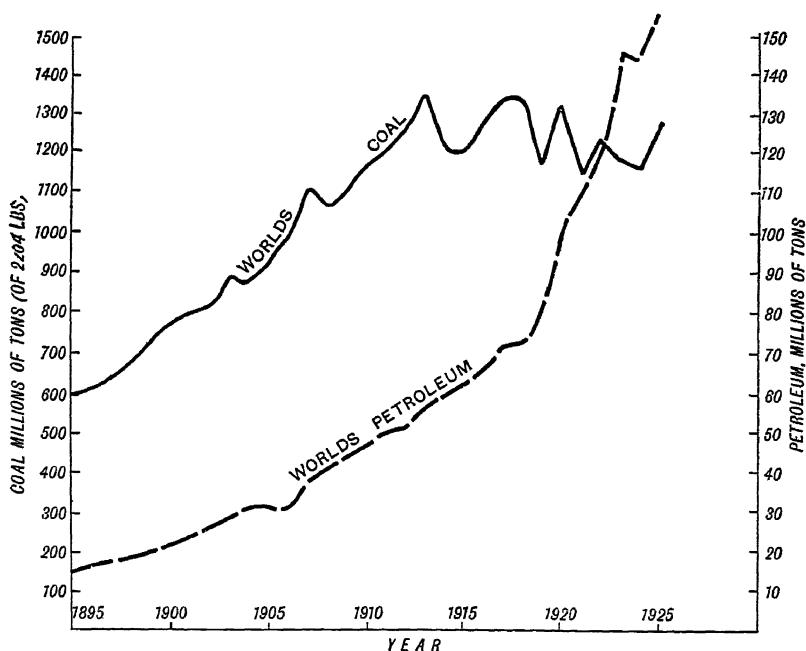


Fig. 1.—Curves showing World Output of Coal and Petroleum since 1895 on Different Scales (1925 figures are approximate).

from 1918 to 1923, would be so high that it would mean selling the oil at a loss; or, to put it the way it comes about, if no loss is to be incurred, the cost of producing oil at so fast a rate of

increase would necessitate selling prices sufficiently high to curtail the demand, hence the rate of increase of oil production could not be maintained. This statement is based on the fact that the most obvious and easily accessible oil-

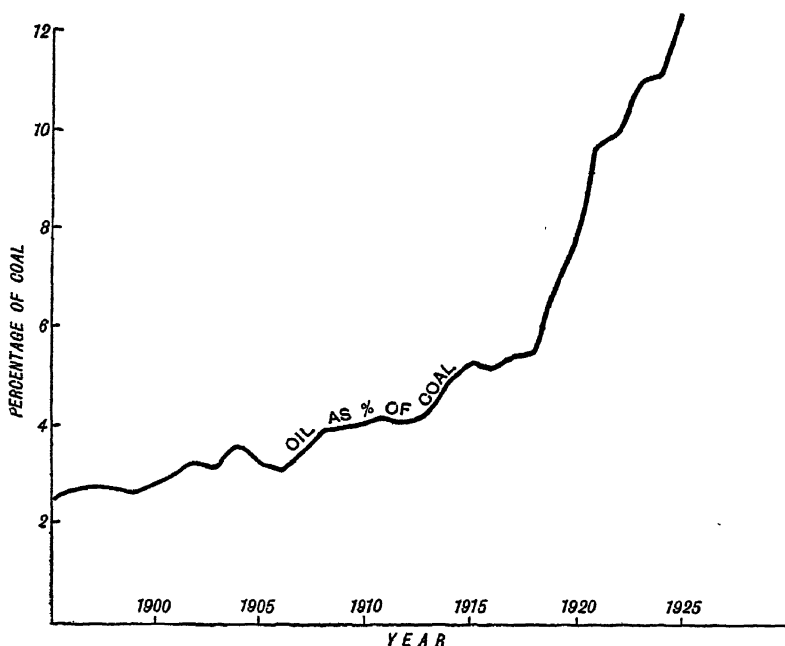


Fig. 2.—Curve showing World's Petroleum as a Percentage of World's Coal since 1895 (1925 figures are approximate).

fields are on the decline, and the improvement in production methods, together with the discovery of new oilfields, is taking place at a slower rate than the rate at which the known supplies of oil

are being depleted. In these circumstances coal seems destined to retain its position as the chief fuel in the world for a long time.

In Great Britain coal has been worked at its outcrops and used since Roman times, but only on a very small scale until the last three centuries.

By the year 1350 coal was being dug at the outcrops of most of the coalfields of Britain, and was used for domestic heating in those districts, but it was not till after the year 1600 that coal finally replaced wood for domestic heating throughout the country.

The smelting of *iron* was carried out in Sussex by the ancient Britons before the Roman conquest. For this purpose wood charcoal was used, and continued to be used, till about the year 1600, when the forests south of London were rapidly nearing depletion. Meanwhile several attempts at smelting iron with coal had proved failures, or had only partially succeeded. Finally, however, towards the end of the seventeenth century success was achieved, more than a century after the first patents on this subject were taken out.

Tremendous expansion of the iron and coal industries took place in the nineteenth century. This was made possible by the introduction of the hot air blast for *blast furnaces* in 1828, which

initiated modern blast furnace practice. Then followed in 1855 *Bessemer's* system, which enabled steel to be manufactured cheaply. These improvements led to the rapid development of steam engines and the introduction of railways and steam-driven ships. Gas lighting was also introduced soon after William Murdoch had shown its practicability in 1792. All these engineering accomplishments rapidly led to Great Britain's position of industrial supremacy in the world, a position which she retained till the close of the nineteenth century. Such unprecedented industrial advancement would not have been possible without the country's great natural resources of coal and iron.

Just as the history of coal owed its importance to iron and steel, so the history of petroleum has been interdependent on the evolution of the *internal combustion engine*. It is most instructive to trace very briefly the main stages in the development of the petroleum industry. Its beginning was very similar to that of many other great scientific factors in our life now, various discoveries that oil could be obtained by distilling bituminous or carbonaceous materials were made independently in several countries, but commercial success was not achieved till a very long time after the first recorded of these discoveries.

In 1681 *Becker* took out a patent in England for obtaining pitch and tar from coal, and incidentally produced coke, but apparently this important discovery was far ahead of its time. Various other similar discoveries were made in subsequent years till finally, more than a century and a half later, in 1847, *James Young* studied a natural occurrence of petroleum in the coal measures of *Derbyshire*, which led eventually to his founding the Scottish oil shale retorting industry. This subject is further discussed in Chapter VI.

In the United States the first bored well is supposed to have been drilled by the *Ruffner brothers* in West Virginia about 1806. The object was to obtain brine; it was drilled with a percussion bit, was cased with wood, and reached a depth of 58 feet. The success of this work led to the drilling of numerous wells for brine, and percussion drilling became thoroughly established.

It was noticed that wells bored for brine nearly always produced also the objectionable substance petroleum, which frequently occurred in sufficient quantity to necessitate the closing of the salt works.

The medicinal value of petroleum had been recognised long before this, and the fact that it could be burnt in lamps was recorded at various

times during the previous (18th) century and subsequently. It was also known, at any rate before 1845, that petroleum could be used as a lubricant.

Perhaps the most important discovery of this time was made by *S. M. Kier*, who in 1849 found that petroleum from a brine well 500 feet deep at *Tarentum, Pennsylvania*, could be distilled to give an illuminating oil and a heavier product. The true significance of this discovery was probably eclipsed by the success of Young's retorting methods in Britain and the United States. In 1855 *Benjamin Silliman* made a fractionation and distillation on scientific lines of a sample of oil from the Oil Creek region of Pennsylvania. Silliman's work showed the wonderful possibilities of natural petroleum in the market already created by the "coal oil" produced by the retorting companies. It was *Drake's* appreciation of these possibilities at their true value at that time which led, after many delays, to the drilling of the first well ever put down for petroleum in the United States. In 1859 Drake, using the methods standardised by the brine drillers, completed at *Titusville, Oil Creek, N. W. Pennsylvania*, what is reputed to have been the first oil well ever drilled in the United States. It is clear from the foregoing that Drake's discovery was more in the nature of an indispensable link in

a chain of evolution. The novelty of what Drake did lay not so much in the drilling, as in the object which he and his associates had in view. Wells were drilled during more than half a century previous to the drilling of the Drake well: moreover, they bored to considerable depths; for instance, in 1814, a well was bored for brine on *Dutch Creek*, West Virginia, to a depth of 475 feet, and periodically discharged oil and gas in considerable quantities. Many other wells were bored for brine, and many of them produced petroleum before 1859. None the less, Drake's entirely new application of the brine drillers' methods led to the discovery of some of nature's vast underground stores of liquid fuel, and resulted in the widespread use of motor cars and aeroplanes, and has in consequence revolutionised the habits of civilised nations within the last few years.

Far-sighted as those early pioneers were, little could they have realised then the truly enormous flow of wealth which they had started from beneath the earth's surface, nor the epoch-making nature of the changes to be brought about by the result of this flow.

Drake's success was immediately copied by others, and as a result all the works established in the United States for obtaining oil by *retorting* very soon ceased operations. Fortunately, how-

ever, it was found that the plant was, with small modifications, suitable for *refining* the natural petroleum obtained from drilled wells. In this manner disaster for these various companies was averted. As production of oil from wells steadily increased in the United States, it began to be exported to Britain. This, together with the expiry of *Young's* patent, resulted in the price of lamp oil in Britain falling from 2s. 6d. to 1s. 6d. per gallon, and sometimes to 1s. per gallon. Between 1871 and 1873 the number of companies retorting shale in Britain fell from 51 to 30, but, due to improvements and economies, the industry still survived. In the earlier retorts sulphate of ammonia was not produced for sale, but the value and large possible yield of this by-product was realised, and in fact in latter years it was due to this by-product that the industry survived at all. This matter is further considered in the chapter on retorting.

Drake's discovery swamped the American market with oil, so much so that during the period of readjustment of demand to supply much of the oil produced ran to waste. The total production for the year 1859 was estimated at 2,000 barrels, and by the end of 1861 it had risen to 15,000 barrels daily. The creation of markets did not keep pace with this rapid expansion, and prices fell so low that production

decreased continuously during the period 1862-1865, till in the latter year it amounted to less than 4,000 barrels a day.

In 1869 the first well drilled for oil in *Russia* was put down in the *Baku* region.

The encroachment of petroleum in fields previously exclusively the domain of coal was to be expected, on account of the much greater ease of handling and economy of the former, and on account of the internal combustion engine. Most notable in this respect is the case of shipping, where oil firing has replaced coal firing in practically all the important passenger-carrying lines. A further advance has now been made and, several passenger vessels are driven by Diesel engines, using the oil directly in the most economical way at present practicable. On cargo boats, the balance of operating cost is a more delicate one, and the use of oil for steam raising is mostly confined to ships trading from a base where local production of oil enables it to be obtained relatively cheaply. *Diesel engined* cargo boats, however, have been successfully operated for many years, and are being built in rapidly increasing numbers. In 1914, 90 per cent. of the world's merchant shipping used coal exclusively, and in 1925 less than 60 per cent. did so. Of the total tonnage of new shipping building in the world, in 1925 for the first time, the proportion

to be propelled by Diesel engines exceeded that to be driven by steam.

As in the past half-century, the importance of liquid fuel has been increasing with unprecedented rapidity, so in the immediate future it appears that nothing can arrest its continued progress. The problem, therefore, of obtaining supplies to meet this ever-increasing demand is one which requires preparedness years before a shortage is imminent. That there need be no shortage of liquid fuel for centuries must be clear from the following chapters. Whether there will be a shortage, at any rate of a temporary nature, or not is another matter, and one on which opinions differ. What cannot be disputed, however, is that every additional supply of oil which is obtained from shales, cannel, torbanites, etc., not only helps to conserve the natural petroleum in reserve, but generally affords a supply which may be looked on as relatively of a permanent nature, on account of the known and measured quantities of these raw materials for the production of oil being vast in extent.

Fuel is only second in importance to food to modern humanity, and prolonged and world-wide cessation of supplies of fuel would not only entail the death by starvation of millions of human beings, but would shake the foundations of civilisation vastly more than any war could

do. Moreover, the continued progress of civilisation appears to be inextricably woven with continued supplies of fuel and the degree of efficiency with which they are utilised. It is, therefore, impossible to exaggerate the importance of fuel, and in particular liquid fuel, to everyone.

It is only intended here to study coal as a raw material for producing liquid fuels, but inasmuch as the majority of present processes convert at the most 10 per cent. of the coal into tar, the subject cannot be detached from the question of the residue of coke. The retorting of coal is dealt with in the chapter on retorting, but a few words may be said here on the other problems at issue.

The Fuel Research Board state that low temperature carbonisation of a wide range of British coals gives on an average $14\frac{1}{2}$ gallons of tar per ton of coal. Judged by modern practice, this is a very conservative figure. Of this tar, 1 to $1\frac{1}{2}$ gallons will be light spirit suitable for motor fuel, while another $1\frac{1}{2}$ to $3\frac{3}{4}$ gallons of spirit per ton of coal may be obtained by scrubbing the gas. It may be said, therefore, that 3 to 4 gallons of *motor spirit* and 12 to 14 gallons of tar are obtainable from the average British soft coal in use. In addition, about 30 therms (3,000,000 B.Th.U.) of high calorific value gas (about 750 B.Th.U. per cubic foot) are liberated,

and 15 lbs. of *ammonium sulphate* may be obtained if so small an amount seems worth the cost of recovery. Taking the bituminous coal burnt in Great Britain in the raw state as 60 million tons per annum, it is seen that 200 million gallons of motor spirit are obtainable from it annually by suitable treatment. This quantity is nearly half the total amount of motor spirit imported into Great Britain in 1925. The fact that this motor spirit is actually available in such large quantities is often quoted, but hitherto the cost of getting it has prevented any large output from this source. To what extent this liquid fuel may be obtained in future depends on :—

1. The price of natural petroleum, with which it must compete.
2. The capital cost of the plant necessary to obtain it.
3. The selling price of the semi-coke which is made in the process.

As each ton of coal gives about 14 cwts. of *smokeless fuel* besides the tar, motor spirit and gas, it is clear that the sum of these products must pay the cost of the original coal, together with all the charges which accrue in making it into these various products. Of the many factors which enter into this balance, the most important

is the disposal of the smokeless fuel and its price. Smokeless fuel undoubtedly possesses advantages for most purposes, domestic or industrial, for which raw coal is now used, but unless a ton of smokeless fuel costs little or no more than a ton of coal, it appears to have no chance at present of widely superseding coal.

The most obvious advantage of smokeless fuel is that it would mitigate the smoke menace. The people of Great Britain are so used to smoke that it is difficult to rouse them to a proper realisation of the direct damage to every clean surface on which the soot falls, and the probably much greater damage to health due to the unnatural exclusion of light, and specially sunlight, by the smoke-laden atmosphere. Messrs. des Voeux & Owens calculated that each year in London 260 tons of soot fall per square mile. Professor Cohen found that in Hunslet, an industrial part of Leeds, soot fell at the rate of 450 tons per square mile per annum. It was also estimated that smoke deprived Leeds of 40 per cent. of its daylight in a year. Bone has pointed out that domestic soot contains about 25 per cent. of tar, as against only 2 per cent. in factory soot, hence domestic soot adheres much more strongly to surfaces on which it falls. Various calculations of the annual direct damage due to smoke have been made, and they run

into millions of pounds. A clean atmosphere would cause a reduction in the country's annual artificial light bill, which would amount to a very large sum.

In view of the above facts, continuation of the smoke nuisance must be considered no small indictment against the progressiveness of any nation which tolerates it. The difficulties in the way of cleansing the British atmosphere, it must be admitted, are great, but something has been done, and there are signs that the voices of the few who have been advocating this for years are at last being heard. In New York the matter was taken in hand thoroughly and drastically, and a comparison of the average atmosphere of that city with that of London is bound to convince any unbiased person of the advantages of this form of cleanliness.

The greater the use of low temperature *semi-coke* for domestic and industrial purposes, the nearer will be the approach to eliminating smoke. Moreover, it has been proved that the average domestic grate is considerably more efficient with smokeless fuel than with coal. Its use, therefore, will be brought about if supplies be available at a price comparable with that of coal, and if steps be taken to educate the general public as to the advantages of its use. It is to be hoped that the efforts of pioneers who

have been for years evolving retorts will not go altogether unrewarded. They are now able to produce satisfactory smokeless fuel, and some awakening of public opinion in the matter of smoke would soon lead to a demand for this fuel, which should ensure commercial success.

An additional very important and desirable point in connection with the adoption of *smokeless fuel* is that, as already mentioned, the manufacture of each 14 cwts. of this semi-coke releases 3 to 4 gallons of motor spirit, and 12 to 14 gallons of tar. The tar will provide *burning, lubricating, Diesel* and *fuel oils* and *pitch*, as well as *phenolic* substances which might be worked up to form to some extent substitutes for petroleum products. There is no need to emphasise the desirability of obtaining home-produced oil, both on account of the employment it gives, and on account of reducing the country's dependence on imported liquid fuel. The achievement of these objects, together with the reduction of smoke, would be so beneficial to Great Britain that a serious national effort is justified.

Lack of knowledge, prejudice, the fate of more than one large-scale attempt at retorting, and propaganda, have been formidable obstacles to any new attempts to obtain oil by these methods. None the less, the need for every industrial country to be as far as possible self-supporting

in the matter of liquid fuel, the economic advantage of a home supply, and the profits to be made by the application of right methods in right localities, are bound to lead to the recurrence of attempts in this direction, and unless the price of oil falls materially success is within sight.

CHAPTER II.

COAL.

It is fortunate that, at the present stage of the advancement of humanity, man has at his disposal enormous quantities of potential heat and power in the form of coal. Had there been no coal, the use of iron and steel would have been still very restricted, and the industrial age with which we are so familiar could at best have barely achieved its smallest beginnings, and might have been deferred for centuries. It is really on *iron* that much of modern progress is founded, and when iron was smelted by charcoal, the limited available or possible local supplies of that fuel imposed a very low limit on the output of iron. When, however, it was found that nature had supplied coal in lavish quantities, and that this coal could be used for smelting iron ores, there was no longer any limit to the amount of iron which could be produced; the iron and steel industry then commenced its period of vigorous development, till it is now the greatest industry in the world, and has carried along

nearly all the inhabitants of the earth in its headlong progress.

The use of coal has increased at such a phenomenal rate during the last half-century that, although there is no fear of any shortage within the next few centuries, it is most desirable that the best use should be made of the coals which are being worked. It is generally admitted that average present-day practice leaves much to be desired, and that very great economies can be made by modernising plant in accordance with known scientific and commercially successful developments.

Although coal is such a familiar object to most civilised peoples of the world, there is still controversy regarding details in its mode of origin, while its great complexity has so far prevented chemists from giving anything approaching a complete statement of the composition of its constituents.

In the general term coal is included the range, lignite, brown coals, caking and non-caking bituminous coals, semi-bituminous and semi-anthracitic steam coals, anthracites, cannel coals and torbanites, and all the intermediate classes by whatever name they are known.

There was once some doubt as to whether *torbanites* should be classed as coals, but microscopic work has shown that there is a wide range

of substances from torbanites, through torbanitic cannels, to the more usual types of coal. Torbanite, however, will be more and more recognised as a special substance to be differentiated from coal on account of the extraordinarily high yields of oil to be obtained from rich varieties when retorted.

It is universally agreed that coal has been formed from pre-existing vegetation which was buried during contemporaneous cycles of sedimentation, and compressed and consolidated along with the sandstones, shales, and other beds with which it is associated.

Here it will be necessary to give the barest outline only of the processes of coal formation, as the subject has been very fully treated in many text-books and other publications.

The first essential for the formation of coal was and is a period of growth of vegetation of sufficient duration to allow of the accumulation of vegetable debris. This might occur in a swamp forest, a forest, a moor, a marsh, or a peat bog. In any of these cases as the life cycle of the trees and plants proceeds, they shed leaves or spores or both according to their type, and finally they themselves die and fall. If this continues in a locality for thousands of years, and particularly if the earth's surface is there subsiding at a rate approximately equal to that at

which the vegetable debris tends to raise the surface, the ground water level will remain constant in relation to the growing vegetation, and growth will be uninterrupted. Any acceleration of the rate of subsidence will result in a gradual advance landwards of the sea, and the resultant deposit of sands and muds on top of the bed of vegetation. If, however, the subsidence ceases and elevation of the surfaces sets in, the forces of erosion will commence their activities, and unless protected by another period of subsidence, the whole of the accumulated vegetation will in the course of time be removed by the processes of disintegration and denudation, which are always at work on every surface exposed to the atmosphere.

From the foregoing it will be realised how delicate is the balance between rate of accumulation of vegetable debris and rate of subsidence of the surface, to enable a potential coal bed to be formed in coastal regions. Slightly too great subsidence will result in much mud and sand with relatively little vegetable debris, to subsequently form carbonaceous shales with sandstones, shales, etc., whilst too little subsidence or slight elevation, will result in the removal of the entire deposit. This is well borne out by actual measurements in any coal field, for instance in North Staffordshire the Coal Measures are about 11,000

feet thick, but of this thickness only a few hundred feet are coal. Or, to give specific examples, in the *Cheadle* coal field, out of a thickness of 1,550 feet of Coal Measure, a total of 46 feet of workable coal occurs in fifteen different seams. In the bituminous region of *Pennsylvania*, a thickness of over 4,000 feet of coal measures contains a total of only 110 feet of coal in some thirty seams.

As areas of intense vegetation are generally flat and often little above the sea level, it is to be expected that they will show frequent signs of contemporaneous local erosion due to the shifting of stream courses. A stream running through the vegetable debris will remove it in its course and leave a deposit of silt in its place. These river deposits, subsequently consolidated, are now familiar to coal miners under the term "washouts," forming local interruptions of shale, sandstone, etc., in otherwise continuous coal seams.

Existing coal beds are considered to represent something of the order of 25 per cent. of the original weight and 10 per cent. of the original bulk of the woody debris from which they originated. The "Dudley Thick" or "*Ten Yard Seam*" of South Staffordshire, of which the average thickness is 30 feet, must consequently have resulted from an original deposit of vegetation 300 feet thick.

The principal geological period of coal formation in the world's history was the *Carboniferous*, which includes the most important coal fields of *Europe, America, and China*. The slightly later coals of *Permo-Carboniferous* age in France, South Africa, India, Australia, etc., are of much less importance, as also are the *Tertiary* coals of Central Europe, Russia, South America, etc. The *Cretaceous* formation in Western Canada and the United States of America contains enormous deposits of coals of many different grades. Although these four periods comprise the main deposits of the world, coals or lignites occur more or less throughout the geological periods from Devonian onwards, but it was in the Carboniferous (including Permo-Carboniferous) times that the greatest activity in the deposition of coal occurred.

It is often suggested that in Carboniferous times the atmosphere contained a much greater proportion of *carbon dioxide* than at present. Practically the whole of the carbon in coal has been derived from the atmosphere. During life vegetation assimilates carbon dioxide from the atmosphere, and the carbon is incorporated in the tissue of the plant or tree. Vegetation which, after death, is buried and preserved to subsequently form coal, retains most of the carbon which, in the form of carbon dioxide, it derived

from the atmosphere during its life, hence the atmosphere loses this amount. It may well be seen, therefore, how the abstraction of carbon dioxide by vegetation over most of the world's land surface acting throughout geological periods of millions of years, must have tended to reduce the amount of that substance in the atmosphere. On the other hand, combustion or oxidation, animals and other causes, are always supplying carbon dioxide to the atmosphere, so that the proportion present only changes to the extent that these two opposite causes fail to balance each other. The whole subject is too complex to enter into here, but it has been supposed that a humid atmosphere with a large content of carbon dioxide would promote much more rapid growth of vegetation than is seen to-day.

"*Coal Measures*" is the term applied to the sequence of rocks in which coal is found. They are invariably shallow water deposits composed of sandstones, shales, clays and limestones, the first three generally predominating. The coal beds themselves are interspersed at unequal intervals throughout the Coal Measures, and vary from almost invisible partings to the thickest seams known. The workable coals, generally so-called if they are 12 inches or more in thickness, usually occur at a number of different horizons in the Coal Measures. Frequently two

or more coal beds will approach and recede from each other in vertical section and sometimes join up to form one seam. Sometimes a coal seam persists for hundreds of square miles, sometimes it thins out and dies away, but may be replaced by another one at a different horizon. Coal is liable to differ in quality in different layers of a seam at any particular point as well as in different parts of the same seam. Just as the coal seams vary in thickness, so also do they vary in quality from slightly carbonaceous shale, through highly carbonaceous shale, to coal. *Carbonaceous shales* merge into coals with very high ash content, forming low-grade fuels.

Cannel coals and torbanites are generally found in contact with coals, but on account of their special properties they are dealt with in another chapter (Chapter III.).

Coal measures frequently contain bands of blackband *ironstone*, which form a valuable ore of iron, and are capable of giving in addition up to 18 gallons of tar oil per ton, recoverable by suitable treatment. As these ironstone bands are generally in contact with cannels, the oil content will be much greater in proportion to the amount of cannel included and its richness in oil.

When speaking of coals, it is generally only the coals which are sold which are referred to.

In the Coal Measures, however, the wide gradation of fuels, varying from shales with only a trace of carbonaceous matter, through carbonaceous shales, to the high ash coals, are becoming progressively more important. In some cases the utilisation of low-grade fuels will enable certain thin seams of good coal to be worked, which by themselves are too thin to support the cost of mining.

The coals utilised fall into the following rough classification :—

TABLE I.

Coal.	Fixed Carbon.	Volatile.	Use.
Anthracites and semi-anthracites.	Per cent. 90-95	Per cent. 3-12	Steam-raising and domestic stoves.
Anthracite and semi-bituminous.	80-90	12-15	Steam-raising and industry.
Bituminous, . . .	70-90	12-35	Coke and gas manufacture and domestic grates.

In commercial tests of coal a dried sample is heated in a small closed crucible to a dull red heat, and the loss of weight in ten minutes is calculated as a percentage of the original coal,

and called the "Volatile."* What remains behind is "Fixed Carbon," which is, of course, combustible. It should always be stated whether the figures have been calculated on the ash-free samples or not.

In addition, there are the cannels and torbanites, of which the former are still used in places for gas manufacture, and the latter give a particularly high yield of liquid hydrocarbons when subjected to low temperature distillation.

In most of the existing appliances for the utilisation of coal, its value rapidly decreases with increasing ash content. This has resulted in enormous quantities of low-grade fuels being either left in the mines or else discharged on waste heaps at the collieries. In the cases where these low-grade fuels are tipped as waste material, the total cost of their handling has to be borne by the coal, whereas if they were utilised, a considerable cheapening in the winning of the coal would result. But perhaps most of the low-grade fuel is left in the mines and never disturbed, or only used as waste material for supporting the roof, etc. The elimination of the waste of at least some of these low-grade fuels is one of the urgent problems now facing the coal industry, and indeed it is one of the details on which national prosperity depends, because only with the highest attain-

* See p. 59.

able degree of efficiency can prosperity be assured.

As the best coals get worked out, there is a tendency for the grade of coal mined to deteriorate. Mr. J. B. C. Kershaw * has given some illuminating figures showing the increasing ash content in the coal consumed by one of the large London power stations. In 1914 the *ash* removed was 11·9 per cent. of the coal used, in 1918 it was 17·3 per cent., in 1919 21·3 per cent., and in 1920 22 per cent. In the case of the last year given in these figures, more than one-fifth of the coal purchased was not only absolutely valueless as fuel, but imposed a heavy cost in bringing it to the station and in its subsequent removal and disposal. This is one of the factors in the problem as to the conditions in which it is more economic to transport the coal and generate electric energy at the point where it is required, as against the conditions in which it is better to generate the energy at the colliery, using cheap low-grade fuels, and distribute it, perhaps long distances, to the consumers. These figures also indicate why the separation of mineral matter from coal by washing or other means, before it is supplied to the consumer, must be carried out to an ever-increasing extent.

* *Fuel*, February, 1924.

CHAPTER III.

TORBANITES AND CANNELS.

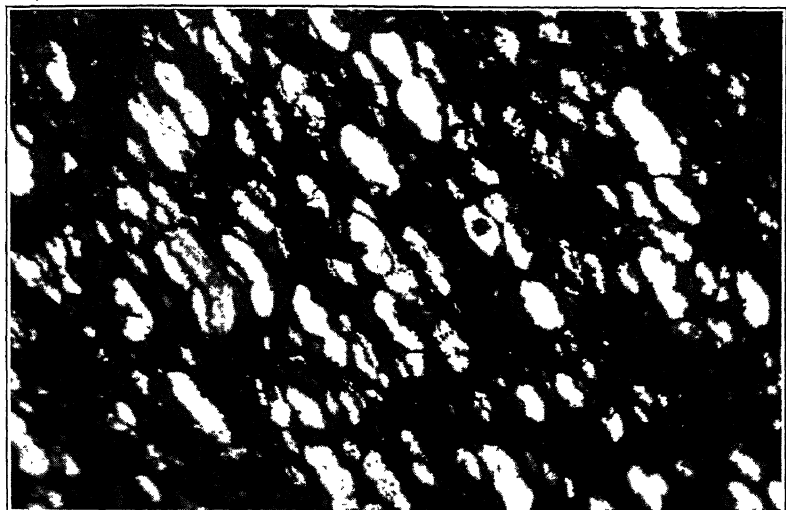
THE occurrence of cannel coals and torbanites is always in association with Coal Measures, generally in actual contact with coals, but occasionally not in contact with them. Torbanites were at one time regarded as coals, but during the last few years microscopic work in particular has led to their classification as a separate group with distinct and unmistakable properties. There are many classes of cannel coals and torbanites with varying degrees of torbanitic development, thus the series coal, canneloid coal, true cannel coal, torbanitic cannel, and torbanite represents successive stages branching off from coal and ending in torbanite.

Cannel coals and torbanites were always deposited as *lenticular* masses, rarely more than 2 feet thick, which from a maximum thickness thin away and die out in all directions. They are considered to have been formed in ponds or lagoons, generally situated within a region of growing vegetation. When the ponds were deep enough to prevent vegetation growing with roots

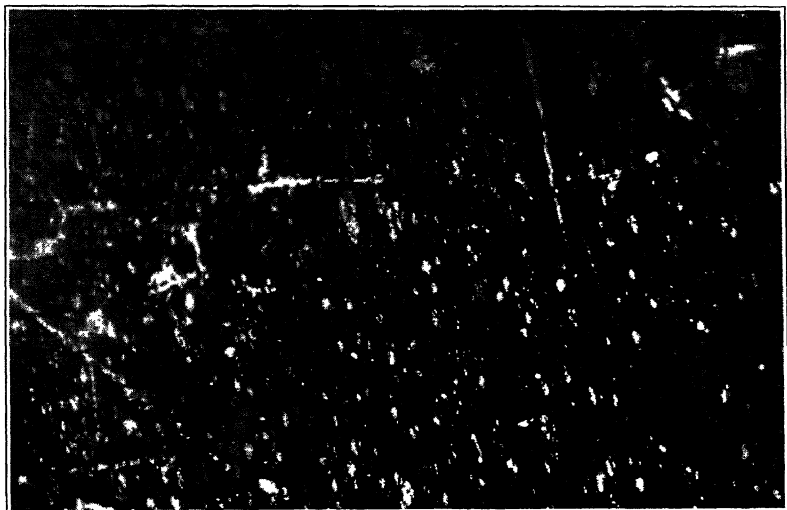
PLATE I.

“Oil and Retortable Materials”—Halse.

[To face p. 30.]



A. TORBANITE.



in the soil below, the only possible sources of supply of vegetable debris would be algal and similar types of growth in and under the water, plants on the surface of the water, or organic and inorganic matter carried in by the wind and water.

It will be realised how variations in the proportions of material supplied by each of the above sources, together with the variations possible in both the wind-borne and water-borne material would allow of the accumulation of raw material the composition of which might show considerable dissimilarity in different lagoons. It seems reasonable to suppose that these initial differences, and especially that of the amount and composition of the inorganic constituent, together with subsequent differences in treatment due to some deposits being more deeply buried, or more highly compressed by earth movements than others, are sufficient to account for the variety in the canneloid and torbanitic products known now.

Rich cannels and torbanites are generally easily distinguishable from coal by their appearance. They are dark brown to black in colour, with a dull to satiny lustre. They do not soil the fingers, and break with a splintery to conchoidal fracture. When scraped with a knife, the resulting powder or "streak" is yellow to dull brown. Planes of lamination are frequently difficult to detect in the hand specimen, but after

retorting or weathering, the substance shows a thinly laminated condition. Both cannels and torbanites light easily on application of a flame, and burn with a smoky luminous flame. They do not intumesce with the heat of combustion, but burn with a crackling noise, which has given rise to the term "parrot coals," by which they are known in many mining districts.

The *specific gravity* of a rich torbanite will be about 1.15 or a little greater. Increasing specific gravities will denote decreasing qualities till at a specific gravity of about 1.3 torbanites merge into canal coals. These figures can only be regarded as giving general indications, as there may be fairly wide divergence from them in some cases. *New South Wales* torbanites range in specific gravity from 1.01 to 1.5 or more, both of which limits are well outside the average figures given above, but the exceptionally low specific gravity indicates an exceptionally rich torbanite, and in fact it is one of the richest known in the world, while the high limit will refer to poor bands only slightly, if at all, torbanitic in character. For comparison British bituminous and semi-bituminous coals are mostly of specific gravity 1.26 to 1.31, while American coals of the same class average about 1.32 specific gravity. Anthracites vary from 1.33 to 1.48 specific gravity.

Seyler* has shown that in coal the specific gravity is increased nearly .01 on an average for each increment of 1 per cent. in the ash content, and that it decreases as the hydrogen or volatile contents of the coal increase. In this respect cannels and torbanites are similar to coals.

The term torbanite is derived from Torbane Hill in Scotland, where the special properties of the substance were first recognised, but it is only in recent years that it has been realised that the Coal Measures of Great Britain contain many other seams of torbanite and torbanitic cannel. The main characteristic of torbanites from the point of view of their utilisation, is the high yield of gas or oil which may be obtained from them by suitable methods of treatment.

To understand what a torbanite really is, it will be necessary to study briefly its mode of origin. In recent years *Cunningham Craig* has made a special study of this subject. Commencing with the now generally accepted theory that the debris of terrestrial vegetation when entombed during a cycle of sedimentation may give rise to coal or oil according to the relative dominance of a number of imperfectly understood reactions due to such conditions as temperature, porosity of strata, inorganic matter in the vegetable debris, etc., he shows how tor-

* *Practical Coal Mining*. Edited by W. S. Boulton, 1907.

banite occupies an intermediate position between coal and oil. He makes the generalisation that in a geological formation which contains petroleum, coal, etc., the free petroleum will occupy the lowest beds, upwards this will give place to a zone which may contain petroleum, coal and oil shales, which will in turn pass up into the coal and lignite zone proper, in the lower part of which the torbanites occur. These phases, of course, overlap more in some cases than in others, whilst there is occasionally no apparent agreement with the arrangement, possibly due to the presence of only one or two of the members of the sequence, or to sporadic occurrences outside their normal environment.

If coal and oil are both formed mainly from the same raw material, there must have been sometimes limiting conditions which would not completely form either coal or free oil. This is the rôle that Cunningham Craig, as the result of geological observation and microscopic research, has found torbanites to occupy. It is not possible here to go into the complete argument, for which the original works should be consulted.* Briefly,

* *Oil Finding*. By E. H. Cunningham Craig. 2nd Ed., 1920. *British Mineral Oil Industry*. Edited by J. Arthur Greene. According to H. R. J. Conacher, the yellow bodies are fragments of resin (*Trans. Geol. Soc. Glasgow*, 16, Pt. 2, 1917), while Jeffrey (1910-15) regards them as macro-spores of vascular cryptogams.

it was found on microscopic examination that torbanites are characterised by a matrix of coaly matter sometimes with some jetonised vegetable remains, and a number of round or ovoid bodies of bright yellow to dull brown colour. These are globules, once known as "*kerogen*," but distinct from the "*kerogen*" of oil shales, and their formation subsequently to the deposition of the rock is proved by the fact that bedding planes never conform to or encircle them, but that they have developed entirely regardless of such planes. *Spores* and other vegetable fossils may not always be sufficiently well preserved to distinguish them from *kerogen*, but the recognition of some spores or *algæ* has sometimes led to the deduction that all globules are spores or *algæ*, a deduction which lacks satisfactory proof. He points out that spores and *algæ* and other vegetable matter entered the rock as original constituents, whereas the globules only developed at a later stage as the result of temperature and pressure on the uncarbonised vegetable matter.

The ash of torbanites is found to approximate in chemical composition to that of a good *fuller's earth*. The value of fuller's earth is due to its property of absorbing and adsorbing oils, which is in turn due to the clay of which it is composed being in a *colloidal* state (*i.e.*, composed of particles of ultra microscopic dimensions). This

property of colloidal clays is being utilised more and more in refining petroleum. The significance of the fact that the inorganic material of a rich torbanite is a colloidal clay becomes apparent when one considers what is likely to happen to petroleum forming from the uncarbonised vegetable matter in an environment of colloidal clay. Referring to the kerogen globules of torbanites, *Cunningham Craig* says:—"These globules are simply incipient drops of petroleum which have formed *gels* with the inorganic colloid material as they came into being, and we have thus preserved for us one of the stages in the formation of petroleum, the action being arrested almost as soon as it has commenced." * He also points out that once coal or lignite is formed, it cannot be transformed into petroleum except in special circumstances such as would arise when a hot intrusive igneous mass comes into contact with the coal. Moreover, once petroleum is formed in nature, it cannot be transformed into coal, but further mineralisation may form it into an asphaltite such as manjak, albertite, gilsonite, or whatever be the local name applied. These substances are used in industry for making paints, especially for marine purposes, as an electric insulating material, etc.

It will be understood from the foregoing that

* *Oil Finding.*

the term torbanitic refers essentially to the globules or gels of kerogen, originating from nascent petroleum and inorganic matter, which have been developed in substances which, without these gels, would have been classed as cannel coals or carbonaceous shales. These globules may be seen from the microscope sections to be closely packed throughout the substance, as in the case of a very rich torbanite, or to be only thinly disseminated as in the case of a low-grade cannel. There are all grades of intermediate varieties, and the boundary between torbanites and cannels is a purely arbitrary one, which is placed by Cunningham Craig at 20 per cent. of kerogen—*i.e.*, substances of this class with more than a 20 per cent. kerogen content would be classed as torbanites, and those with less as cannels or canneloid substances. The *amount of oil* which may be obtained by distilling cannels or torbanites will be roughly proportional to their kerogen content, but it will also be affected to some extent by the coaly matrix, especially the jetonised or uncarbonised portion of it. An approximation to the relative proportions of these constituents is readily made by their appearance under the microscope, in particular closely packed gels denoting a high yield of oil.

The works quoted make it clear that only

when uncarbonised vegetable debris is accompanied by the requisite conditions of temperature, pressure and sealing in the presence of suitable colloidal inorganic matter, can torbanitic development take place. If any one of these conditions is lacking, torbanite cannot be formed, and it appears that the number of factors and their balance is much more delicate if a torbanite is to result, than if carbonisation to coals or lignites is to take place, hence coals and lignites are of much more frequent occurrence than torbanites and torbanitic cannel.

As far as producing oil only is concerned, the most important substances in the coal mines are the cannel coals, torbanitic cannel and torbanites. As these substances always occur in association with coal or interbedded with coal, their winning as a raw material is essentially part of coal mining. Cannel were used in the United States on quite a large scale during the period 1855 to 1860 for retorting for oil, and for the same purpose in Great Britain till a somewhat later date. E. M. Bailey* states that cannel coal was distilled for oil in Britain by one company up to 1895. The development of the free oil resources of the United States, how-

* "The Scottish Shale Oil Industry," by E. M. Bailey. Paper read before the Diesel Engine Users' Association, 9th October, 1925.

ever, meant the end of the retorting of cannel coal for oil for the time being. The use of cannels for the manufacture of town gas is still practised to a small, but diminishing, extent; the rather higher ash content of cannels leads to a dirty coke, which is moreover much more friable than coke from average gas coal, and so suffers from inferiority in two different respects.

It is easy to see how cannels have been lost sight of in the coal mining industry, or perhaps it is more correct to say that they are now mostly assessed on their value as ordinary coal, and their special properties, on which their potential value depends, have been almost entirely forgotten. In Great Britain it is now most desirable that the cannels come back into their own—*i.e.*, that instead of being utilised as ordinary coal or being dumped on the waste heaps of collieries or being left in the mine, they be brought to bank with the coal with which they occur, and be retorted locally in order to obtain the 30 to 60 gallons of oil per ton available from most of them. The *retorting*, being carried out for the purpose of obtaining the maximum of liquid products, would be conducted at a low temperature—*i.e.*, below 600° C.—and the *gas* formed, being of high calorific value, is consequently valuable either to sell or to use. The profitable use of the residue in the retort is an important item, especially

when the lower grade cannels are being worked. In general, on a large scale, it would be most economical to gasify it completely, and possibly to recover the nitrogen as ammonium sulphate. This would result in a large output, something of the order 75 to 100 thousand cubic feet per ton of cannel, of low-grade gas, of calorific value about 130 to 150 B.Th.U. per cubic foot. Gas of this calorific value is used in large quantities for industrial purposes in various types of furnaces, for steel, glass, boilers, etc., and for internal combustion engines. The limitation imposed, therefore, is that the plant must be situated where the gas is required. Each plant would in any case be close to the group of collieries supplying the cannel, and as the big industrial areas are also in the colliery regions, the above limitation would not appear to be in any way detrimental.

On account of cannels having been "forgotten," statistics as to the amount available are not easily obtained. During the war, however, the *Petroleum Research Department* went fully into this matter, and not only compiled data as to the cannels available in Great Britain, but also made tests to ascertain their oil yield. Apart from this, it is well known that there are several colliery waste heaps containing large amounts of cannel coals, and that the yield of

some of these is up to 60 gallons of oil per ton. It is also well known that if there were a market for them, many of the cannels at present wasted could be mined with the coal with which they occur, and could be sold profitably at low prices. The amount of cannel available is, of course, not comparable with the amount of coal available, but it has resulted from conditions which frequently occurred during the periods of coal formation, consequently the existence of cannels in coal measures is normal and widespread. Incidentally their mode of formation renders them generally lenticular and not very thick, and on this account the mining of cannels alone is only undertaken in the relatively unusual circumstances of a very thick or exceptionally rich seam. This is, no doubt, one of the reasons which accounts for the opinion which has been expressed that cannels are rare in Great Britain.

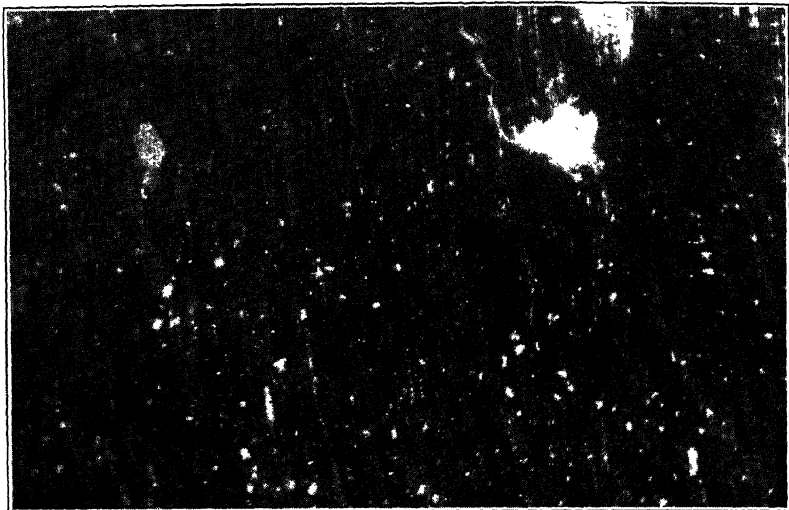
The prospects of profitably obtaining oil from cannels do not lie so much in resuscitating this industry in its past form of mining the cannels alone for retorting, but rather in eliminating waste and utilising cannels wherever they are obtainable in sufficient quantities in suitable localities. At the present price of oil, and at the present stage of evolution of low temperature carbonisation, the retorting of average cannels for oil should be profitable if the price of the

raw material is moderate. As already mentioned, many cannels are separated from their associated coals and treated as waste material for want of a market for them. The cost of this has to be borne by the coal. If a purchaser could be found for them, even at very low prices, the efficiency of the particular mines would be increased. In this manner cannels should be available at prices sufficiently low to allow of their utilisation for retorting.

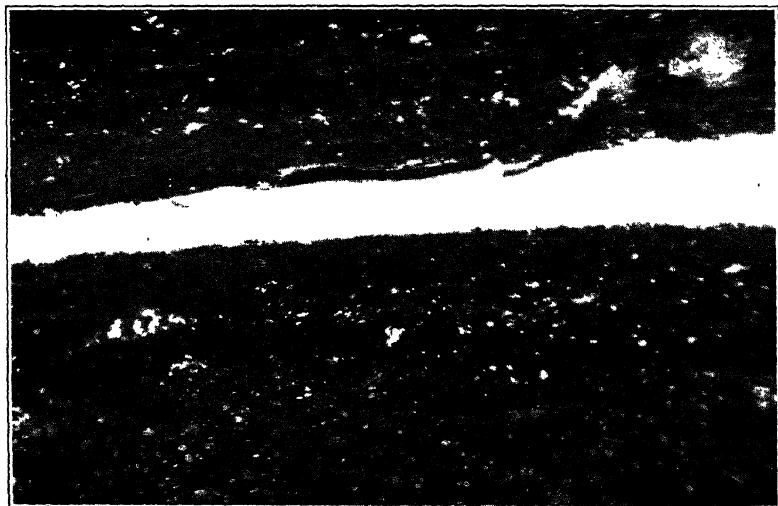
PLATE II.

“ Oil and Retortable Materials ”—Halse.

[To face p. 43.]



A. BROXBURN SHALE.



CHAPTER IV.

OIL SHALES.

THE term oil shales will here include only those substances which are strictly oil shales, and will not include torbanites, which are frequently, though improperly, called oil shales.

An oil shale is a shale which at some period in its history has been impregnated with petroleum. It is a special variety of shale, or a shale with special properties, much in the same way as torbanite is a special form of coal. Two shales may have exactly similar inorganic compositions, but one may be an oil shale and the other not an oil shale, simply because the former was impregnated with oil from external sources or from the genesis of oil within the shale itself, whilst the latter received no oil at all, and hence could not become an oil shale. The inorganic composition of the shale is an important factor in both the readiness with which it will absorb and adsorb the oil if available, and the tenacity with which it will retain it. If two neighbouring beds of shale come in contact with the same

supply of oil, the one with the greater *colloidal* characteristics will take up the greater amount of oil initially, and will also hold it much more strongly than the shale with lesser colloidal properties. The origin of the petroleum does not enter into this aspect of oil shale. Whatever origin be ascribed at any given point, other conditions being equal, the oil will show its preference for the colloidal clay material. Consequently, a rich oil shale is almost invariably light in weight, so much so that a practised geologist will by merely handling a sample be able to form an opinion as to whether it is likely to prove rich or poor in oil. Lightness in weight alone does not necessarily indicate a rich oil shale, as it may be merely a colloidal clay which has never received any impregnation of oil.

Under the *microscope* an oil shale appears totally different from a cannel or torbanite. It is seen to be a fine-grained detrital rock, coloured light yellow to dark brown by the oil with which it has been impregnated. A small proportion, varying in different shales, can be extracted by solvents and can be called "free oil"; the bulk of the oil is adsorbed by colloidal inorganic matter, and can only be released by some form of retorting, involving destructive distillation. In oil shales the microscope shows a general staining of the rock by oil, whereas in the tor-

banites the oil-giving bodies appear as numbers of small separate yellow bodies in a dark coaly matrix.

The figures in Table II. show the general relationship between the specific gravity of a shale and its yield of oil.

The calculated specific gravity of the inorganic content is obtained by assuming the specific gravity of the oil to be $\cdot 92$, and that of the kerogen in the original shale to be $1\cdot 05$. The amount of kerogen in the shale is thus obtained, and by abstracting this proportionally the specific gravity of the mineral matter is calculated. Assuming all the tests quoted to have been made under similar conditions, slight errors in the inorganic specific gravity will be present, because no account is taken of the incondensable gases, so that in each case the true inorganic specific gravity will be very slightly greater than the figure shown. Making the most liberal allowance for errors and differences in the tests, it remains indisputably apparent that the lighter the weight of the shale the greater its content of oil. The light weight of a shale is connected with a high development of colloidal characteristics, and, as already mentioned, its richness is due to the much more marked affinity of petroleum for colloidal than for non-colloidal clays.

Such causes as the juxtaposition of a colloidal

TABLE II.—RELATIONSHIP BETWEEN SPECIFIC GRAVITY OF OIL SHALES AND THEIR YIELD OF OIL.

Authority	Publication.	Locality.	Specific Gravity of raw shale.	Oil yield British Imperial gallons per ton.	Calculated specific gravity of inorganic content.
E. H. Cunningham Craig.	<i>Journ. Inst. of Petroleum Technologists</i> , vol. viii., p. 352, July, 1922.	Esthonia.	1.2-1.4	70-80	1.41
R. M. McKee and E. E. Lyder.	<i>Journ. Indust. Eng. Chemistry</i> , vol. xiii., Nos. 7 and 8, 1921.	Parachute Creek, Colorado.	1.60	52.8	1.75
D. R. Steuart,	<i>Oil Shales of the Lothians</i> .	Fells Shale, Pentland, Scotland.	1.66	47.72	1.81
"	"	Dunnet Shale, Pentland, Scotland.	1.76	36.84	1.88
"	"	"	1.82	33.00	1.94
"	"	"	1.92	29.10	2.04
"	"	Pentland, Scotland.	2.00	23.27	2.10
"	"	Broxburn Shale, Pentland, Scotland.	2.10	17.22	2.18
"	"	"	2.19	16.10	2.27
"	"	Dunnet Shale, Pentland, Scotland.	2.3	14.58	2.38
Shatwell, Nash & Graham.	<i>Journ. Inst. of Petroleum Technologists</i> , London, vol. x., p. 876.	Somerset Shale, England.	2.41	10.12	2.47
"	"	"	2.49	5.0	2.52

with a non-colloidal clay in a single specimen, the presence of calcareous fossils, the pressure and temperature to which the shale has been subjected and a number of other factors, as would be anticipated, cause a considerable variation in some cases from the figures given in Table II. Considering, however, the infinite number of different sets of circumstances possible during and subsequently to the formation of oil shales, it seems very remarkable that the variations in the relationship between specific gravity and yield of oil are not greater. Plotting data given by the authors named in Table II., together with figures given by *Dean E. Winchester*, it will be found that the points all lie between the two lines drawn on Fig. 3.

The chemistry of colloids is daily becoming more important, and the application of the properties of colloids in treating petroleum, as well as many other substances, is extending so rapidly that some understanding of colloids is essential.

Briefly, a *colloid* is a substance, not any special substance, which is in an extremely finely divided state. *Boydell's** definition is:—" 'Colloidity' is a general property belonging to the colloidal state of matter, and, contrary to former belief,

* *Bulletin Institute of Mining and Metallurgy*, London, No. 243, December, 1924.

there is no separate class of substances called colloids. Given the proper conditions (which vary), all substances may be prepared in the

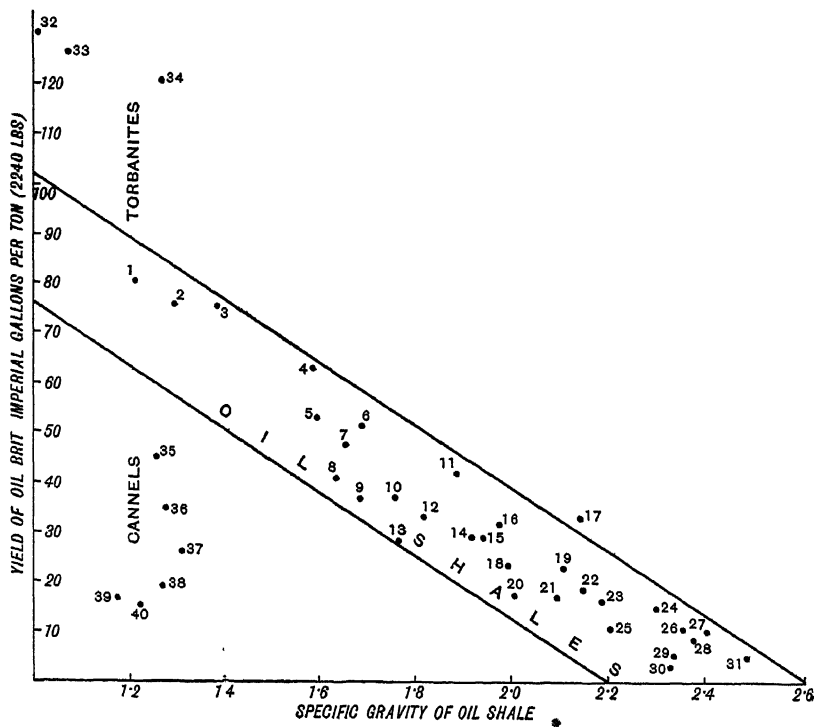


Fig. 3.

RELATIONSHIP BETWEEN SPECIFIC GRAVITY AND YIELD OF
OIL OF OIL SHALES.

colloidal state. The colloidal (or colloid) state of matter, therefore, takes its place with the better known, but really no more important,

gaseous, liquid and crystalline states.” “Colloidal solutions or, as they are commonly called, ‘*sols*,’ occupy an intermediate position between true solutions on the one hand and coarse suspension on the other, there being fairly well defined limits of a more or less arbitrary character

OIL SHALE.	OIL SHALE.	CANNEL AND TORBANITE.
1. Flintshire.	14. Scottish.	
2. Esthonia.	15. Scottish.	32. Hartley, N.S.W., Torbanite.
3. Green River, Colorado.	16. Scottish.	33. Hartley, N.S.W., Torbanite.
4. Green River, Colorado.	17. Flintshire.	34. Torbanite Hill, Torbanite.
5. Colorado.	18. Scottish.	35. Hartley, N.S.W., Torbanite.
6. Green River, Colorado.	19. Scottish.	36. Flintshire Cannel.
7. Scottish.	20. Powell Co.	37. Cannel.
8. Kimmeridge.	21. Scottish.	38. Northumberland Cannel.
9. Green River, Colorado.	22. Scottish.	39. Carter Co. Cannel.
10. Scottish.	23. Scottish.	40. Greenup Co. Cannel.
11. Green River, Colorado.	24. Scottish.	
12. Scottish.	25. Green River.	
13. Kimmeridge.	26. Somerset.	
	27. Somerset.	
	28. Somerset.	
	29. S. Wales.	
	30. S. Wales.	
	31. Somerset.	

to the range of colloidal solutions within the disperse system. In some cases there are almost continuous transitional stages from one end to the other of the system.” Colloids occupy a sort of transition or intermediate stage between a mechanical mixture and a true or chemical

solution, and their characteristics are largely due to their very large surface, which results from their extremely fine state of division. R. J. Sarjant* states that 1 lb. of coal in the lump form has a surface of $\frac{1}{4}$ square foot, but if this pound of coal be pulverised so that 95 per cent. of it passes a 100-mesh sieve and 82 per cent. a 200-mesh, its surface becomes 8,000 square feet, or 32,000 times the surface of the single lump. Carrying this *pulverising* much further enormously augments the increase of surface, and when it is sufficiently large the colloidal state is reached. A colloidal clay is any clay composed of particles so small that they make it behave as a colloid.

It will be readily appreciated what a perfect colloidal mill a river or a seashore may make. Sand or rock debris is continuously being ground against itself and against other rocks by water action, and the water carries away the fine material, and sorts it according to size, the larger particles dropping wherever the current slows down, and the finer material being carried out to sea. The finest material is often so small in size that it would remain in suspension indefinitely if its deposition depended on the weight of the particles only. There are, however, known to be reagents, particularly *electrolytes*, which

* *Fuel*, January, 1925.

cause deposition of these ultra-microscopic particles, and by their action a bed of colloidal clay may be deposited.

As already explained, colloidal clay strongly *adsorbs* and *absorbs* petroleums and other greases and oils. Perhaps the best known application of this is the use of *Fuller's earth*, which is a colloidal clay, to remove grease from cloth in the process of manufacture, but its property of selective adsorption applied to *de-sulphurising* and *de-colourising* petroleum which is passed through it is now of the greatest importance in the refining of oil. In a colloidal clay which has absorbed and adsorbed petroleum, the absorbed portion can be recovered by solvents, but the adsorbed portion, which is usually by far the greater of the two, can only be driven off by heat. An oil shale is exactly similar in this respect, and just as in refinery practice, the clay is roasted to drive off the adsorbed compounds, so in an oil shale, the application of heat releases the adsorbed petroleum, and, of course, vaporises and drives off the absorbed portion at the same time.

A typical oil shale will only give up part of its oil content to solvents. *David T. Day** states that 60 per cent. of the bituminous content of *Nevada shale* may be separated in this way.

* *Handbook of the Petroleum Industry*, 1922.

*D. R. Stuart** found that *Scottish* and *New Brunswick shales* yielded 1.95 per cent. and 2.33 per cent. respectively to a solvent made up of light shale spirit and ether in equal proportions. *Cunningham Craig* states that the *Kimmeridge* shale of Dorset gives up to 32 per cent. of its oil to solvents, 5.34 per cent. of its weight.

The removal of the adsorbed organic matter, which has been termed "*kerogen*," together with the absorbed portion, is the object in view in retorting an oil shale. The heating of the shale promotes chemical reactions of a complex nature, transforming the "*kerogen*" into condensable and incondensable gases with the release of a certain amount of free carbon. The aim will always be to obtain the maximum proportion of condensable gas, which, of course, condenses into crude shale oil.

Geologically, *tar sands* are in many respects analogous to oil sands. At any rate, they are generally agreed to be sands which have been impregnated by petroleum, which, on account of stagnation of the petroleum and access of air or both, has become *inspissated*—i.e., thickened by the loss by evaporation of the lighter constituents—and to some extent oxidised.

As the tar in typical tar sands is a sticky viscous mass at ordinary temperatures, the usual methods

* *Oil Shales of the Lothians*, 1912.

of obtaining petroleum cannot be applied successfully to them, whereas methods similar to those used in obtaining oil from oil shale may be operated satisfactorily.

A tar sand looks just like sand or sandstone which has been dipped in tar. If a sample be held in the hands they become soiled with the tarry oil. If the sand be heated, the tar becomes fluid and a lot of it will run out of the pores of the sand. Treatment with solvents such as carbon bi-sulphide will remove practically the whole of the tarry matter from the sand, showing that it is present as a simple impregnation of the pores between the individual sand grains.

There is no hard and fast line between typical tar sands and sand or sandstone outcrops impregnated with petroleum. Instances from various parts of the world prove the one to merge into the other by gradual stages. A sandstone impregnated with an asphaltic and slightly inspissated petroleum may be classified by one observer as a tar sand and by another as merely an outcropping oil rock. In fact, the latter may become an instance of the former after prolonged weathering.

Amongst the north-western foothills of the *Pyrenees* in northern *Spain* in the region of the *Cordillera de Cantabria*, including *Vitoria*, *Logrono* and *Pamplona*, extensive outcrops of oil-

impregnated sandstone or tar sands occur. They may be seen at intervals over an area stretching for more than 50 miles from north to south, and more than 100 miles from east to west. The thickness of the beds of tar sand is in places as much as 40 feet. At *Maistu* and *Atauri* the outcrop of the tar sand is worked, the rock being cut into rectangular blocks and used for street paving. As the workings penetrate into the rock the impregnating tar becomes more fluid, like a very heavy petroleum, and consequently the rock becomes insufficiently cohesive and solid to be used for paving.

At the little town of *Penacerrada*, during the war, a somewhat primitive form of still was installed to obtain oil from the tar sand of the vicinity. About three barrels of oil per day were produced here till the close of the war, but the plant was too inefficient to continue operations when oil prices fell.

In the United States, the best known examples of tar sands or outcrops impregnated with heavy oil are the *brea beds* of *California*. In other states also similar occurrences are known, and suggestions for extracting the oil have been made from time to time.

The biggest and best known occurrence of tar sands is that of the *Athabasca* river region of Alberta, Canada. These sands are as much as

220 feet in thickness in places, and their area is about 10,000 square miles. Without many more bores or shafts through the overburden, neither the area nor the thickness can be stated with accuracy, but the extensive outcrops along the Athabasca River and its tributaries prove that actually in sight there is oil in sufficient quantity to supply the whole world for many years. The tar sands are almost horizontal, or have a dip of not more than 10 feet to the mile towards the south. The Athabasca River has in many places cut through them to their base, where they may be seen to lie uncomfortably on a Devonian limestone series. The overburden varies from practically nothing to several hundred feet in thickness, but there are many hundreds of square miles in which it is thin enough easily to allow of stripping by steam shovels. The oil content is variable, but an average of fully 14 gallons to the ton (British measurements) may be relied on.

There are a number of methods by which the oil or tar may be separated from the sand, such as :—

1. Retorting the sand, when the oil is driven over in the form of vapour and then condensed.
2. Heating the sand in some liquid which will either dissolve out or float out the contained oil.

3. Heating the sand *in situ*, to cause the oil to flow by gravity, enabling it to be collected.

All of these methods are successful in that they extract the oil, but until the world price of oil is higher it appears improbable that the products from the Athabasca tar sands will be able to support the heavy transport charges to enable them to reach world markets at a profit. They should, however, be able to supply local markets to a growing extent.

CHAPTER V.

CORRELATION OF FUELS.

ALL fuels belong to the organic or carbon substances in nature. The carbon compounds may be very roughly classified in ascending volatile contents, as follows :—

TABLE III.—CLASSIFICATION OF ORGANIC COMPOUNDS.

Diamond, . . .	Pure carbon.	Hardest substance known.
Coal, . . .	Mainly carbon, with hydrogen, oxygen, etc.	Solid.
Vegetation, . . .	Cellulose, etc.	Solid.
Asphalt, . . .	Hydrocarbons.	Plastic.
Petroleum, . . .	Hydrocarbons.	Liquids.
Natural gas, . . .	Hydrocarbons.	Gas.

This arrangement merely indicates the physical state of the great organic groups. It now remains to subdivide them and show how all, except the diamond, may be traced back to vegetation, which may include a certain amount of animal matter.

It does not appear to be generally realised how

great is the variety of the available coals and carbonaceous substances, nor how they merge from one to another by imperceptible changes. If analyses of carbonaceous shales, coals, and anthracites be tabulated according to carbon content, a series of hundreds of members may be formed ranging from shale containing negligible amounts of carbon to anthracite composed almost exclusively of carbon. The low carbon members of this series (except certain iron ores) are all waste material, but the dividing line between waste material and coal is a variable one dependent on plant available, mining details and commercial considerations, and what may be discarded as waste material in one locality may be used as a *low-grade fuel* in another. Table IV. shows this gradation of fuels in a limited way for commercial coals in Great Britain. The composition of the combustible matter is calculated after eliminating ash, moisture, and sulphur, so that all the instances given are technically but not commercially comparable. For commercial purposes the ash and *sulphur* are very important, but as ash in coal is mainly adventitious in origin, having resulted for the most part from the deposition of water-borne silt on or with the debris of vegetation when it originally accumulated, it does not enter directly into the chemical composition of the coal sub-

stance. The volatile combustible matter is the weight of the gases driven off when the dry fuel is heated and expressed as a percentage of the weight of the original fuel. If the fuel be not properly dry, or contains hydrous minerals which do not give up their water at the usual drying temperature of 105° C., this will be contained in the volatile: for instance, *kaolin* and *calcium sulphate*, if present in the ash, will give up adsorbed water and water of crystallisation respectively when heated. *Carbonates* will give up carbon dioxide gas and iron pyrites will be converted into ferric oxide. All these changes involve a loss of weight which, unless separately calculated, will be erroneously included as volatile in proportion to the amount of the various substances in the coal. In commercial practice, however, these corrections are not usually made for coal, since the chemical analysis is somewhat laborious, and the error in any case is only small. With oil shales, on the other hand, carbon dioxide may introduce a very considerable error in shales of a calcareous nature, and a correction must be made to get the true volatile combustible matter.

There are now internationally accepted standardised methods and apparatus for carrying out the tests. It is most important that these be adhered to for ascertaining the volatile content, which varies for a given coal according to the

TABLE IV.—CHEMICAL COMPOSITION OF COALS, LIGNITES, PEATS, ETC.

Material.	Authority.	Specific Gravity.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Volatile.
			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Dry wood, . . .	J. S. S. Brame.	.48	49.2	6.1	44.2	.51	...
Dry peat, . . .	J. S. S. Brame.	.21 to 1.3	58.5	5.5	32.7	3.0	...
" . . .	"	...	60.4	6.5	32.0	0.94	...
" . . .	"	...	62.1	6.8	30.0	1.08	...
" . . .	Cornet.	...	64.07	5.01	26.9	4.0	...
Lignite, . . .	J. S. S. Brame.	.5 to 1.5	55.9	6.48	37.6	...	46.3
" . . .	W. A. Bone.	...	63.0	6.26	28.6	.5	65.0
Altona Victoria lignite.	Morwell.	...	67.1	4.55	27.4	.7	27.6
Bovey Tracey lignite,	V. B. Lewes.	...	69.5	5.91	24.56	...	...
Gardanne lignite, . . .	"	...	73.31	5.06	14.0	1.63	...
Bohemia lignite, . . .	Laurentz.	...	81.47	8.71	9.82	...	...

TABLE IV.—CHEMICAL COMPOSITION OF COALS, LIGNITES, PEATS, ETC.—Continued.

Material.	Authority.	Specific Gravity.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Volatile.
S. Staffs. coal,	Elsden & Griffiths.	1.22	Per cent. 79.0	Per cent. 5.31	Per cent. 14.4	Per cent. 1.3	Per cent. 30.5
Leicester coal,	"	to	79.4	5.26	14.1	1.27	32.3
N. Staffs. coal,	"	1.35	80.0	5.02	13.2	1.67	34.4
Scottish coal,	"	...	85.6	6.11	7.0	1.54	31.5
Somerset coal,	"	...	86.5	4.74	8.72	...	19.7
S. Wales coal,	"	...	89.7	4.79	4.06	1.22	27.2
"	"	...	92.5	4.57	1.66	1.13	12.14
Scottish anthracite,	Elsden & Griffiths.	1.33 to	93.5	3.76	1.91	.9	9.43
S. Wales anthracite,	"	1.5	95.6	3.04	.51	.77	...
Shungite,	...	2.0	...	...	...	...	...
Graphite,	...	2.26	96	...	...	...	...
Diamond,	...	3.1 to 3.5	...	...	...	...	...
Petroleum,	...	.82 to .98	86 to 88	12 to 14	.01 to 6.9	...	100

amount of coal used in the test, the rate at which it is heated, the temperature to which it is heated, and the duration of the heating. Similarly, for any other tests standardised methods tend to introduce equal errors, so that the results may be compared much more satisfactorily than if different methods are used.

A number of figures are given in the above table in order to show the many irregularities which the sequence contains. Since, however, these fuels are all products of original vegetable raw material, it is clear that the process of *coalification* involves concentration of carbon, at the expense of hydrogen and oxygen, particularly the latter. Graphite and diamond are put in for comparison. It is not suggested that all *graphite* was formed similarly to coal, but it seems to be agreed that beds of graphite, as distinct from veins, are extreme cases of the mineralisation of previously coaly matter. *Diamonds* are put in the table because, like coal, they are formed of carbon, but it is not implied that either the original material or the subsequent processes are analogous in the two cases.

In trying to place the cannels and torbanites in Table IV., it soon becomes evident that they cannot be made to fit into the sequence. A rich torbanite will have 80 per cent. carbon, 11 per cent. hydrogen, and 7 per cent. oxygen, on the

ash-free basis, while a cannel differs mainly from this in its much lesser hydrogen content. The torbanites as regards their carbon and oxygen content are akin to the lesser mineralised coals, but in hydrogen they are much nearer average crude petroleum. Typical Scottish torbanite has an ash content of about 20 per cent.; but it may vary widely. In spite of these wide variations, no torbanite is known which does not contain a fair amount of ash, whereas many coals have been found practically ash free. Moreover, coals with a carbon-oxygen ratio similar to that of torbanite can be found almost ash-free, and with increasing degrees of ash up to and over 20 per cent., but their properties render them very easily distinguishable from torbanites. This indicates that the torbanitic characteristics are connected with the *inorganic* mineral matter, and that in this respect coals are entirely distinct, for the properties of the coal substance are independent of and unconnected with the ash, most of which may be separated by suitable mechanical means. Another characteristic of torbanites is their extremely high content of volatile matter, which is far in excess of that of coals, and this makes them particularly suitable for producing oil or gas by distillation.

Tables V. and VI. show that the cannel coals are intermediate between true coals and tor-

TABLE V.—SOME RELATIONSHIPS BETWEEN COALS, CANNELS, AND TORBANTES.

Authority.	Locality.	Carbon ratio Hydrogen.	Volatile Combustible.		Material.
1. Elsdon & Griffiths,	S. Wales.	31.5	...	Per cent.	Anthracite.
2. " "	Scotland.	24.8	...	9.43	
3. W. A. Bone, .	S. Wales.	20.7	...	5.97	
4. Elsdon & Griffiths,	"	20.2	...	12.14	Steam coal.
5. " "	Somerset.	18.3	...	19.73	
6. " "	Northumberland.	17	24.9	...	Steam, gas, and coking coals.
7. " "	"	16.8	...	32.1	
8. " "	S. Yorks.	16.2	32.73	...	Coals with canneloid properties. Steam, gas, house, and coking coals.
9. " "	Lancs. & Cheshire.	15.1	...	36.6	
10. " "	Derby.	14.9	...	39.4	
11. " "	S. Staffs.	14.5	30.5	...	
12. Vause, .	Wigan cannel.	14.4	...	39.6	
13. Elsdon & Griffiths,	Gloucester.	14.0	...	35.8	Cannels.
14. " "	Scottish.	13.1	31.6	...	
15. J. S. S. Brame,	St. Helens' cannel.	11.9	...	52.7	
16. G. H. Ashley,	Glendale, Utah.	11.0	...	49.7	
17. " "	Lesley, Kentucky.	9.65	...	51.6	
18. Miller, .	Lesmahagow, Scotland.	7.98	...	56.7	Torbanites.
19. Slessor & How,	Stellarite, Nova Scotia.	7.47	...	66.5	
20. J. S. S. Brame,	Torbane Hill.	7.2	...	87.8	
21. W. Gibson, .	"		...	61.4	

banites as regards their *carbon-hydrogen ratio* and volatile contents. Besides showing the intermediate position of cannels as judged by their carbon-hydrogen ratio, Table V. also indicates the general continuity of the whole series, showing how torbanites merge into cannels, then into gas coals, followed by a mixed zone of gas and steam coals (Nos. 13, 12, 10, 9), into steam coals, and finally anthracites. Similarly, the other branch of coal (Nos. 14 and 11), which is distinguished from the cannels by its lower volatile content, quickly merges into the mixed zone, where the special properties of the cannel branch are so diminished that, although the main feature of the juncture is unmistakable, the properties of types intermingle and overlap so that precise and definite boundaries cannot be demarcated.

Table VI. shows the relationship between ash and combustible matter in shales, coals, cannels, etc., and merits careful study. For each substance a range is taken from unusually high to unusually low ash content, and in consequence a good deal of overlap of the divisions is observed. Even so, some important distinctions are evident: oil shale stands out from all the other substances on account of its high ash content, and this feature alone is sufficient to distinguish oil shale from all other combustible substances, except carbonaceous shales; while torbanites are

TABLE VI.—SOME DISTINCTIONS BETWEEN COALS, LIGNITES
TORBANITES, ETC.

Authority.	Locality.	Substance.	Per cent. Ash.	Per cent. Volatile Combustible.
1. Sir A. Strahan,	Dorset.	Shale.	85.0	6.2
2. W. S. M'Cann,	New Brunsw- wick.	„	77.8	13.1
3. „	„	„	71.2	18.9
4. Sir A. Strahan,	Dorset.	„	65.2	23.2
5. Mingaye White and Greig.	Scotland.	„	62.3	27.4
6. „	„	„	53.6	37.2
7. M'Kee & Lyder,	Colorado.	„	47.0	53.9
8. E. H. Cunning- ham Craig.	Esthonia.	„	44.0	55.0
9. W. Gibson, .	Scotland.	Torbanite.	29.2	61.4
10. H. How, .	„	„	21.2	71.2
11. J. Woodrow, .	N.S. Wales.	„	20.2	46.52
12. G. H. Ashley, .	Utah.	„	17.0	49.7
13. J. M. Hodge, .	Kentucky.	„	11.7	50.9
14. J. Woodrow, .	N.S. Wales.	„	8.5	75.2
15. Slessor & How,	Nova Scotia.	(Stellarite).	8.2	66.5
16. Elsdon & Griffiths.	Lancashire.	Cannel.	3.7	59.2
17. R. Peter, .	Kentucky.	„	7.3	47.0

TABLE VI.—*Continued.*

Authority.	Locality.	Substance.	Per cent. Ash.	Per cent. Volatile Combustible.
18. Elsdon & Griffiths.	Derbyshire.	„	10.0	42.1
19. C. E. N. Bromhead.	Yorkshire.	„	21.1	31.5
20. R. Peter,	Kentucky.	„	21.5	44.5
21. G. H. Ashley,	Illinois.	„	25.7	41.2
22. F. M. Perkin,	Devonshire.	Lignite.	29.6	37.2
23. V. C. Illing,	„	„	15.6	43.1
24. Babcock & Odell.	Dakota.	„	10.5	42.2
25. „	„	„	8.9	41.5
26.	Fed. Malay States.	„	6.2	43.3
27. Saise,	Calcutta.	Coal.	22.5	34.4
28.	Illinois.	„	14.0	33.3
29. Elsdon & Griffiths.	S. Staffs.	„	10.2	30.5
30.	Pennsylvania.	„	8.23	30.1
31. Elsdon & Griffiths.	Lancashire.	„	7.6	22.0
32. „	S. Wales.	„	4.8	21.0
33.	Pennsylvania.	Anthracite.	8.18	4.28
34.	„	„	6.22	3.08
35. W. Gibson,	S. Wales.	„	.8	4.74

distinguished by their excessive volatile and medium ash content.

It is necessary to emphasise that an *oil shale* is here considered, as in fact it is, as a totally different substance from a *torbanite*. The two terms are frequently used as synonymous, and so long as this practice continues, both the material itself and its environment will be wrongly described, for torbanite occurs typically in association with coal beds, and oil shale, although associated with coal series, typically lies mainly outside the actual coal measures. A torbanite is a special form of coal, as an oil shale is a special form of shale, and to term a torbanite an oil shale, not only implies a quite different substance, but also a different geological assemblage.

In the United States torbanites are generally called cannels or boghead cannels. As has already been pointed out, there is a long gradation from coals through cannels to torbanites, so that torbanites are the richest form of cannel. Whether they be called boghead cannels or torbanites matters little, though the latter term is perhaps more convenient and less liable to allow of confusion. In either case the dividing line between cannels and torbanites remains a purely arbitrary one, and many substances might be classed with one or the other equally well.

In Table VII. are set out the averages of all the figures given in Table VI.

TABLE VII.—AVERAGES FROM TABLE VI.

Substance.	Per cent. Ash.	Per cent. Volatile.
Oil shale,	63.0	29.3
Torbanite,	16.6	60.2
Cannel,	14.9	44.2
Lignite,	14.2	41.5
Coal,	11.2	28.5
Anthracite,	5.1	4.0

This table brings out clearly some of the characteristics which distinguish the group of substances. If the volatile contents of two substances are similar—*e.g.*, shale and coal,—the ash content at once serves to classify them. If a coal be found to contain 63 per cent. ash like the oil shale, its volatile content would be too low to allow of its being classified as an oil shale. The feature distinguishing torbanites from commercial coals is their high ash content and very high volatile content. Cannels may be regarded as being, in that respect, intermediate between torbanite and coal. The lignite-coal-anthracite series has been dealt with in many text-books, and Table IV. indicates the progressive change in the chemical constituents in

accordance with the degree of coalification or mineralisation.

The foregoing remarks make it clear that there is a relationship between oil shales, coals, torbanites, etc., and also petroleum. The view that the combustible matter of all these substances has been derived mainly from vegetation seems to be receiving wider and wider support as new facts are discovered. In the case of petroleum, its liquid form and its liability, amounting to almost a certainty, to move from its original position of formation, render proofs of its origin by direct methods impossible. A discussion of this subject would be out of place here, but it may be said that no serious objection has been raised by geologists or chemists to the possibility of the formation of petroleum in nature from vegetable or animal matter or both. As, however, petroleum is so widespread in sedimentary formation, it has been suggested by Cunningham Craig that the accumulation and entombment of animal matter in sufficient quantity seems unlikely, cannot be proved, and affords no adequate analogy at the present time. Deposits of vast quantities of the debris of vegetation, on the other hand, are abundantly proved to have existed in past times by the enormous deposits of coal into which they have been transformed, and at the present time peat

bogs, tropical swamp forests, etc., are accumulating vegetation which will, under suitable geological conditions, provide supplies of fuel in future ages.

The greatness of the variety of coals and allied substances occurring in one group of coal measures makes it evident that, to obtain the best value from any group of coals, they must be treated by a number of different processes. The more comprehensive the treatment of the coals, the more complete the extraction of fuel from a mine, the more valuable will be the marketable products. In practice, this ideal is generally only distantly approached, on account of the amount of additional plant required and other commercial considerations. A knowledge of the inherent possibilities of coals is the indispensable precursor of their commercial application. This knowledge, therefore, is of the utmost importance to everyone who influences policy in the winning or application of these fuels. The extent to which retorting for oil is possible depends primarily on the quantity of raw material available, its quality, and its accessibility. There can be no doubt that the main reserve of materials suitable for retorting by present known methods is afforded by the vast coal resources of the world. Although research is rapidly widening the possibilities of obtaining oil from coal, at

present the torbanites and cannels give the most satisfactory oil, both as regards quantity and quality. Perhaps the most spectacular work of recent years is that of *Bergius* in *hydrogenating* coals and oils. He uses pressures of 200 to 300 atmospheres regularly, and occasionally pressures up to 5,000 atmospheres, but with temperatures rarely exceeding 450° C. By subjecting bituminous coal to these high pressures and moderate temperatures in an atmosphere of hydrogen, he succeeds in producing a liquid somewhat of the nature of a tar. By similar treatment, heavy oils with very small proportions of low boiling constituents are converted into much lighter oils giving yields of motor spirit comparable in amount to those of the best grade crude oils, or to the yields obtained by cracking.

The Bergius process is one in which the chemical and mechanical problems have been solved, but the present low price of oil does not appear to be conducive to development on a sufficiently large scale to materially contribute to world supplies of liquid fuel. There are other ingenious processes, which are also of proved practicability, and it appears certain that such processes will, in the not distant future, likewise commence to add their quota to existing supplies.

In dealing with coal, although the amount of oil available by retorting (without hydrogen-

ation) is much less than in the case of rich oil shales, this is to a great extent compensated by the fact that the retort residue forms a valuable smokeless fuel. In fact, the main object of low temperature retorting of coal is to obtain a smokeless fuel, though the oil must be recovered if the operation is to be commercially successful. No use is usually made of the residue of shale from retorts: in *Esthonia*, however, shale is burnt in the form of powdered fuel in cement kilns, and the residue is completely used up as an ingredient of the cement. In this case no oil is recovered, the fuel value of the shale being used to supply the heat for the kilns.

The coal resources of the *world* down to a depth of 6,000 feet were estimated by the *International Geological Congress* in 1913 at over 7,000,000 million tons, of which 3,690,000 million are bituminous, and 2,835,000 million are sub-bituminous and lignitic. The bituminous coal alone, on a yield of 10 gallons of oil per ton, contains 165,000 million tons of oil, or enough to last the world over 1,100 years at the 1925 rate of consumption of oil (148 million tons). It is not intended to suggest that oil supplies in general might be obtained from this source, but the figures are given merely as an indication that for the present supplies of fuel are practically inexhaustible. Moreover, the research work

already accomplished leaves little doubt that the yield of oil from coal is likely, as soon as free petroleum from wells becomes scarcer, to be nearly 100 gallons per ton rather than the 10 gallons calculated above.

The oil shale deposits of the world have only in a few cases been measured up, but the figures available suggest that they are almost on as grand a scale as the coal beds. In *Estonia* the workable *kukersite* (oil shale) is estimated, as the result of borings and workings, at 5,000 million tons, which on a yield of 50 gallons of oil to the ton means over 1,000 million tons of oil, awaiting extraction whenever it is required.

In the *United States*, Victor C. Alderson estimates the oil available in the shales of some of the States, as follows :—

Colorado, . .	11,300	million tons of oil	(79,000	million barrels).
Kentucky, . .	2,100	" "	(14,700	").
Utah, . .	6,800	" "	(47,600	").
Indiana, . .	750	" "	(5,250	").
Wyoming, . .	560	" "	(3,920	").
World's oil consumption, 1925.	148	" "	(1,036	").

The liquid oil reserves of the proved areas of the United States available by present methods of drilling were computed by a Committee of the *American Petroleum Institute* at 5,300 million barrels (760 million tons) in 1925. These figures deal with present methods, and the proved oil-

fields only, and do not include new oil fields which are likely to be discovered, but they are quoted to show how, even if the amount of oil which will actually be obtained is four times as great as this figure, the reserves of oil in the form of shale are immensely greater. So far as the United States is concerned, it appears that present supplies of petroleum can be relied on to fulfil the requirements of a few decades only, whereas the oil shales, cannel, and torbanites will suffice for the needs of centuries.

Oil shale in the Kimmeridge clay in the Kimmeridge and Corton district of Dorset, England, has been estimated* to contain (Kimmeridge 455 million gallons, Corton 442 million gallons) $3\frac{1}{2}$ million tons of oil.

The oil shales of *Norfolk*, England, are in the same geological formation as those of Dorset, occurring in the Kimmeridge clay. Undoubtedly, they contain several million tons of oil, but large scale development by English Oilfields, Ltd., after the war was not brought to success. This was partly on account of the high sulphur content (8 per cent. or more) of the oil produced.

Nova Scotia has been estimated to contain 2,000 million tons of torbanite, etc., averaging

* *Imperial Institute Monograph on Oil Shales*, by H. B. Cronshaw. London, 1921.

35 gallons per ton—i.e., 280 million tons of oil.

In South Africa large deposits of rich torbanite have been proved from outcrops and by borings to occur in contact with coal beds.

In *New Brunswick*, Canada, W. J. Wright* says the conclusion is that the Albert Mines area, 4,000 to 6,000 feet long by 1,000 to 1,500 feet wide, is almost entirely underlain by oil shale to a depth of 1,400 feet. Taking the average yield at 40 gallons per ton, this represents some 47 million tons of oil.

In *New South Wales*, rich torbanites have been worked at an average of some 20,000 tons per year from 1885 to 1923. Many of them are very rich, giving over 120 gallons of oil per ton. R. H. Cambage estimates the oil content of the principal deposits at present known at some 12 million tons of oil.

In *Tasmania*, the area known to contain *Tasmanite* (a spore coal) exceeds 100 square miles, but insufficient data have been collected to make exact estimates of the quantity of workable material. About 3 square miles of this in the Mersey district has been estimated by Twelvetreves to contain 12 million tons of shale, or some 1,400,000 tons of oil.

* *Geology of the Moncton Map Area*, Geological Survey. Ottawa, 1922.

In *France*, deposits of oil shales and torbanites are being worked at *Autun*, at Buxière and Saint-Hilaire (Allier), and at *Boson* and *Menat*. The reserves are estimated at 150 million metric tons, containing 10 million tons of available oil. In 1924 the output of shale was 67,000 tons.

In *Gottland, Sweden*, oil shale is being worked on a commercial scale. The reserves are estimated at 5,260 million tons of shale, containing 184 million tons of oil.

In *China*, oil shale occurs in fairly large quantity at *Fushun, Manchuria*, in association with coal. The reserve has been estimated at 5,500 million tons of shale, containing 330 million tons of oil.

In *Germany*, in 1925, low temperature carbonisation of brown coal yielded 90,000 tons, and of bituminous coal 60,000 tons of crude oil or tar, a total of 150,000 tons, or over a million barrels.

It is unnecessary to further enumerate data as to oil shale deposits which occur in practically every country in the world. The point to emphasise is the fact that supplies are ample to provide all the liquid fuel which can conceivably be required for the next few centuries.

What is of immediate importance is not the vastness of the amount of oil reserved in shales,

torbanites, etc., but which of those deposits should now receive special attention with a view to supplementing the oil from wells. As the oil is removed from wells, the supply is not replenished by natural processes, oil being like any other mineral, once it has been removed it has gone for good. There is this difference, however, that, being a liquid occurring in the interstices and cavities in rocks, it is impossible to obtain *complete extraction*, and present methods allow anything up to 50 per cent. of the oil to remain below ground. This merely brings nearer the inevitable time when the supply of oil from wells will be unable to keep pace with the ever-increasing demand. There is only one sure way of averting the possibility of being faced with a shortage of oil, and that is to develop alternative supplies.

CHAPTER VI.

RETORTING.

RETORTING, *carbonisation*, *destructive distillation*, *dry distillation*, are all synonymous terms meaning heating a substance in a closed vessel in order to drive off and collect the volatile products which are released by heat. Part of the volatile products may be condensed to liquids (and solids), and part may remain as premanent gases.

The history of retorting dates back centuries, and the results of subjecting coal to this treatment were discovered and rediscovered various times.

In England, in 1627, a patent was granted to *Sir John Hacket* and *Octavius de Strada* for treating coal in a way which made it a suitable smokeless substitute for burning in houses in place of charcoal. At this time the shortage of wood for fuel in London had become so serious that coal was much used in houses, but the change in fuel caused a lot of apprehension on account of the smoke nuisance. During the ten years from 1627 about ten patents were taken out for different methods of making coal *smokeless*, but no doubt

then, as since then, the raw coal was cheaper than the smokeless coal, and people began to get used to smoke, or at any rate the opposition to smoke was insufficient to keep the smokeless fuel processes alive. It is to be hoped that the present-day efforts to provide industrial and domestic consumers with smokeless fuel in place of raw coal will meet with more success than attended these efforts some centuries ago.

In 1681 *J. J. Becker* and *H. Serle* took out a patent (No. 214) in England for "A new way of making Pitch and Tarre out of Pitt coale, never before found out or used by any other." In 1694 *Eele Hancock* and *Porlock* obtained a patent (No. 330) for "A way to Extract and Make great Quantities of Pitch, Tarr, and Oyle out of a sort of Stone." The stone referred to here is sandstone impregnated with petroleum, which occurs at various horizons in the coal measures of *Shropshire*, down to the top of the Millstone Grit. *Prestwich*, writing in 1837, stated that the well-known tar spring at *Coalport* formerly yielded nearly 1,000 gallons of tar a week. A seepage of heavy oil at *Pitford* is due to impregnation from the Coal Measures sandstones, and incidentally gave rise to the name of Pitch-Ford.

In 1746 *H. Hoskins* was granted a patent (No. 619) for a "New method of extracting a spirit or oyl out of tar, and by the same

Process produce the finest of Pitch.” In this case the crude tar, presumably obtained from coal, was “topped” or distilled into two fractions only.

In 1781 *Archibald, Earl of Dundonald*, in Patent No. 1291, described “A method of extracting or making Tar, Pitch, Essential Oils, Volatile Alkali, Mineral Acids, Salts, and Cinders from Pit Coal.”

In 1819 the *Gas Light and Coke Company* in London were distributing coal gas to consumers, and the coke, which was evidently made at a relatively low temperature, was used a good deal for domestic fuel in place of coal.

In 1830 *Reichenbach* made paraffin by retorting wood.

In France in 1838 *Selligie* patented a process for producing oil from bituminous shale, and within the next seven years his methods had attained a considerable degree of perfection. He produced illuminating and lubricating oils, paraffin wax, and sulphate of ammonia, and his process was patented in England in 1845.

All the foregoing discoveries were ahead of their time, or, at any rate, with the exception of gas manufacture, no one developed them on a large scale till *James Young* took up the subject. It appears probable that Young's discovery was made independently of previous investigators,

though he may have profited by Selligie's work in the refining of the oils he produced.

James Young is generally credited with being the founder of the modern oil industry. In 1847 he studied a natural occurrence of oil in the coal measures at *Alfreton* in Derbyshire. Conditions by this time were more propitious for the introduction of oil, and Young had the perception to realise the possibilities of oil as well as the driving force to carry on, despite setbacks, until success was achieved.

The oil at *Alfreton* led Young to experiment with the distillation of a number of different types of British coal. He found that by heating them in a closed retort, vapours could be distilled off and condensed into liquid tars or oils, differing in type and amount with the raw materials used. Finally, in *Linlithgowshire*, he found the *Torbanehill* "gas coal," as it was called, which gave 120 gallons of crude oil per ton, and in consequence of this high yield the industry for retorting for oil became firmly established. In 1850, Young obtained a patent for "Treating Bituminous Coals to obtain Paraffine and Oil containing Paraffine therefrom." He specified that the most suitable coals for the process are parrot, cannel, and gas coals, and stressed the importance of heating gradually, and of keeping the final temperature as low as possible in order to

avoid making permanent gases at the expense of condensable liquids. His processes of fractionation and subsequent treatment of the oil were much on the lines of usual refinery practice till nearly up to the time of the war. He worked the Torbanehill gas coal (now called torbanite) continuously and successfully till 1862, when the supply at that locality was practically exhausted. Very soon after 1850 Young's process was introduced into the *United States*, where, under license, shales, cannels, or coals from Virginia, Kentucky, and Missouri, as well as some imported Torbanehill mineral, were retorted. By the year 1860 there were 53 of these plants in operation in that country.

In 1862 it became necessary to utilise other materials to carry on the retorting business in Scotland, and oil shales were used. Yields of 45 gallons per ton were obtained at first, but the richest shales were soon worked out, and the yield fell to 30 or 35 gallons per ton. Up till 1864 the price of lamp oil, the principal product, was 2s. 6d. per gallon, and occasionally higher.

In 1864 Young's patent expired, and the shale oil industry of Scotland increased rapidly till, in 1871, there were fifty-one works with a total output of 25,000,000 gallons of crude oil per year. This, however, was the year of maximum output during that period. From this time

onwards, the importation of oil derived from wells in the United States prevented the big increase of the shale oil industry of Scotland which must otherwise have taken place, but it has never yet caused the extinction of this interesting and important industry. In the United States, on the other hand, the production of free oil in that country caused the abandonment of all retorting enterprises for oil. The following figures show the extent of the Scottish shale mining industry :—

Year.	Shale mined per year, long tons.
1871,	800,000
1881,	958,000
1891,	2,361,000
1901,	2,354,000
1910,	3,130,000
1920,	2,842,000
1923,	2,860,563 *
1924,	2,857,103 *
1925,	2,464,829 *

* Figures kindly sent by the Imperial Institute.

Although the output of oil shale in Scotland is declining, the position of the retorting industry at the present is particularly interesting, and it is considered by many people that where suitable material occurs in a suitable locality it will enter a new lease of life in the near future—*i.e.*, when the ever-increasing demand for oil will

have overtaken the hitherto ever-increasing supply. This elusive event has appeared to be on the verge of actually happening ever since the war, but supplies have always been equal to the exceptional demands. The astounding increase of output has been due mainly to the extensive and rapid development of oil production in the *United States*, which country supplies and uses almost three-quarters of the world's oil. As, however, oil exists in definite quantities only, and is not being replaced as it is removed from the earth, supplies have a very finite limit. Finding new areas and deeper drilling are likely to continue supplies of oil from such sources for generations ; nevertheless, the phenomenal increase of consumption is bound to overtake production, some people think within the next few years. It would be mere guess-work to make any prophecy as to when this will take place, and hitherto prophecies regarding depletion of American oil reserves have proved singularly wide of the mark, but the certainty of its taking place is obvious. As drilling gets deeper and in more inaccessible regions of the earth, the price of oil is likely to increase to compensate the increased expense of obtaining and transporting it. Methods of retorting the enormous oil shale reserves are evolving so rapidly that even now, apart from the oil Scottish

industry, some oil is being supplied on a commercial scale from oil shales. There is every indication that oil from shales will increase rapidly in quantity, but the same inducements which bring this about—namely, higher oil prices—also bring about not only fresh activity in drilling for oil, but also increased economy in utilising it.

A *retort* is merely a closed vessel to contain the material to be treated. This vessel is heated to make the material being retorted (coal, oil, shale, etc.) give off gases which are then cooled and condensed to liquids. There are many different methods of construction of retorts, of heating, charging, and discharging them, and so on, but the main underlying principle is always the same.

Retorting is usually undertaken with the object of obtaining the maximum amount either of gas or of liquid products. The former is conducted at a relatively high temperature, and the latter at a much lower temperature.

In *gas works* practice coal is charged into firebrick retorts, and the retort is closed so as to be airtight and the temperature is raised gradually to about 1,400° C. (2,552° F.) in the modern types of retort. The resulting products per ton of coal are :—

Up to 14,000 cubic feet of gas (calorific value about 500 B.T.U. per cubic foot).

9 to 16 gallons of tar (specific gravity 1.05 to 1.2).

20 to 30 lbs. of ammonium sulphate.

12 cwts. of hard coke.

These conditions of retorting give a suitable gas for the types of stoves and burners in general domestic use at present. The coke is unsuitable for burning alone in the open fire grates customary in Great Britain, but it burns perfectly well in closed stoves, and gives no smoke. The ease with which coke or semi-coke will ignite and burn appears to depend on the area of its cell surfaces, a big area allowing ample contact with the gases, and promoting ease of burning. Research work by Sir G. Beilby and others has shown that high-temperature coke is covered with carbon in the vitreous state, and it is chiefly on account of this vitreous carbon that it cannot be ignited easily. Efforts are now being directed towards making high-temperature coke which will be sufficiently free burning for use in domestic grates.

The tar obtained in gas works' practice is entirely different from that derived from low-temperature processes. It is composed mainly of the *aromatic* (benzene) hydrocarbons, with phenols and cresols (oxy compounds), pyridine and its homologues (bases) and thiophene and carbon bisulphide (sulphur compounds). Of these

the benzene, toluene, xylene and some higher homologues are used for motor fuel (known as *benzol*), for the manufacture of explosives, solvents, dyes, drugs, and chemicals. The phenols and cresols are used for *disinfectants*, explosives, dyes, and drugs.

The tar is divided into five main *fractions*, and the further subsequent fractionation and treatment is continued the greater the number of substances which may be obtained, some 400 having been isolated.

- (1) Up to 170° C., light oil containing benzene, toluene, xylene, and higher homologues (*benzol*).
- (2) 170° to 230° C., middle oil, naphthalene, carbolic acid, etc.
- (3) 230° to 270° C., heavy oil, creosote, etc.
- (4) 270° C., till there is no further distillation, anthracene.
- (5) Residue of coal tar pitch (being over 50 per cent. of the original quantity of tar).

As these fuels are not very valuable, the *benzol* content is not much more than 1 gallon per ton of coal, though if the gas be *stripped* of its *benzol* an additional 2 gallons per ton will be obtained. However, it may be better from the gasworks'

point of view not to strip the gas, for the following reason:—Two gallons of benzol have a total calorific value of 260,000 B.T.U., and if the price of gas be one shilling per therm, this benzol as gas is worth 31·2 pence. As crude benzol at one shilling per gallon, it would be worth 24 pence. As gas is now sold in Great Britain by its heat content, and not by its volume, at the above prices it clearly would pay better not to strip the benzol from the gas.

High-temperature tar is valuable chiefly for the numerous chemicals, etc., derived from it, and for its benzol content. Frequently the tar is “topped,” to remove the benzol, and possibly the middle oil may be taken off as well, and the residue is used to tar roads. The tar can, of course, be burnt, but it contains a good deal of “free carbon,” which causes trouble. Certain fractions of the tar may be used for Diesel engine fuel, but they are not applied very much to this purpose.

Complete *gasification* of the coal by a first stage of low-temperature carbonisation and subsequent gasification of the coke will yield 54,000 cubic feet of gas of 380 B.T.U. per cubic foot, or 20,520,000 B.T.U. per ton. *Mond producers*, much used in industry, give up to 150,000 cubic feet of gas of calorific value 130 B.T.U. per cubic foot—*i.e.*, 19,500,000 B.T.U. per ton. A great

advantage of these systems is that low-grade fuels can be used, whereas in gasworks high ash content would make the coke difficult to sell. Also 65 to 75 per cent. of the *nitrogen* in the coal is recoverable by these processes as ammonium sulphate. British gas coals generally contain 1 to 1.3 per cent. of nitrogen. Theoretical complete conversion of the nitrogen into *ammonium sulphate* would give 105 lbs. of sulphate per ton of coal for each 1 per cent. of nitrogen in the coal. In Mond producers yields up to 90 or 100 lbs. of ammonium sulphate per ton of coal are obtained in practice, which is about four times the amount obtained in most gas works.

Retorting in connection with the production of liquid fuels refers more especially to the *low-temperature* processes—*i.e.*, at temperatures up to 500° C. or 600° C. (1,112° F.). As compared with gas works (high temperature) carbonisation, low-temperature retorting of coal gives approximately one-quarter the amount of gas (but of calorific value 700 to 750 B.T.U. per cubic foot instead of 500 to 550 B.T.U.), one-third the amount of ammonium sulphate, slightly more coke (which will burn in open grates), and nearly twice the amount of tar of much lighter gravity.

The form a hydrocarbon will assume is de-

pendent on the temperature to which it is subjected, and this is why high-temperature tars are so different to low-temperature tars. One of the most difficult problems of retort designers is to heat the material being retorted to the required temperature at a sufficiently rapid rate without subjecting the evolving gases to temperatures materially higher than those at which they are evolved. Coals, torbanites, oil shales, etc., are highly *non-conductive* to heat, and it was found in some of the earlier retorts that, while the outer layer of the charge had been raised to the temperature desired and fully coked, the centre had been hardly altered at all.

Another factor of fundamental importance in retorting is the *plastic* or semi-fluid stage through which many coals and shales pass within the range of retorting temperatures. The material intumesces into a sticky mass, and at the same time in many cases expands very considerably, and consequently tends to clog the retort. The mechanical devices employed in some of the earlier retorts to overcome this difficulty would not stand up to the work, and broke down sooner or later, but now devices have been evolved which are capable of doing what they are intended to do. In this connection the point of greatest importance is that a retort which is quite successful with one kind of material may

be a total failure with another kind, and hence that the retort must be specially designed for the actual material or, at any rate, the type of material it is required to treat.

In working in a low-temperature retort, material which leaves an incombustible residue, it will generally be found that the extraction of the last few per cent. of combustible matter in the material being retorted will necessitate more expensive treatment in proportion to the yield from it than is required to extract the bulk of the fuel content. For this reason it is likely often to be more advisable, for the sake of keeping the process as simple as possible and the plant as inexpensive as possible, to waste a small amount of the available fuel in the material. Complete extraction can be obtained, but the value of the small additional extraction is unlikely to be sufficient to meet the additional overhead, depreciation, and interest charges.

In the design of a low-temperature retort, in order to obtain the maximum amount of oil of the best quality, the following objects must be kept in view :—

- (1) The material must be heated gradually.
- (2) The evolved gases must be removed without remaining in contact with hot surfaces.

- (3) The operation of the retort should be continuous, or if intermittent should not involve complete stoppage and restarting.
- (4) Temperature control should be easy and effective.
- (5) For caking material, provision must be made to keep the retort surface clean, and to keep the material moving through the retort, and particularly for non-caking material dust, if any, must be removed by some special device.

To go a little into detail on the above point :—

(1) Gradual Heating.

Consider an individual particle of material in the retort. Whether this particle be heated by contact with the retort surface, by contact with neighbouring hot material, or by a hot gas or liquid, the heat will penetrate from the outer surface of the particle to the interior. When the outer surface reaches a definite temperature, gases will be evolved from it. There will be a *temperature gradient* from the hot exterior surface of the particle to the cooler interior, and the steepness of this gradient will depend on the rate

of heating. The result of this temperature gradient is that gases evolved in the interior of the particle will have to pass through the hotter zone at its surface in order to escape. If the heating be rapid, the surface of a particle will be much hotter than the interior of the particle, and the gases escaping from the interior will be *cracked* as they pass through the outer hot region. If, however, the heating be carried out slowly, the gases on evolution will come in contact with surfaces not much above the temperature at which they are driven off, and cracking will be avoided. This is one of the most important factors in retorts, as it means in effect that it is impossible to heat the material rapidly from outside the retort, hence the number of tons which can be passed through the retort per day is limited by this consideration, and the cost of plant to treat a given quantity of material depends directly on it. It will be clear that for a particle in contact with a retort wall at a given temperature, the time necessary for the heat to penetrate to the interior of that particle depends on the size of the particle. To this case the "*Law of Times*" applies—viz., that, with the surface at a constant temperature, the time required for any interior point to reach a given temperature is proportional to the square of its distance from the hot surface. In other words, a particle twice

the diameter will take four times as long to reach a given temperature. Applying this law to the charge in a stationary externally heated retort at once makes it evident why the charge must be only a few inches thick. If the material be crushed fine, more rapid heating and less cracking will result, because the temperature gradient in each particle will be small, and the escaping gases will heat up other particles by which they must pass. If the material in an externally heated retort be in constant motion, the heating will tend to be more uniform.

If producer gas or a liquid such as oil be used for supplying heat to the material in the retort, the thermal and mechanical conditions are quite different. Since the material is in direct contact with the heating medium, the retort may be charged practically full, and the hot gas or liquid passing through it gives rapid and effective heating. In the case of gas, however, if the charge be at rest, there is a tendency for it to follow channels, which results in unequal carbonisation of the charge, and moreover it is difficult to get a uniform gradient of temperature from the hot to the cool end of the retort.

Any retort, therefore, which aims at producing a good quality oil must be designed so that the material being treated is raised in temperature evenly and slowly.

(2) Quick Removal of Gases.

In the initial stages of the distillation of coal, paraffin hydrocarbons predominate, but if these come in contact with hot surfaces, they are cracked or decomposed, forming the aromatic unsaturated or benzene hydrocarbons. The disadvantages of this are two-fold, first the volume of permanent gas is increased, but at the expense of the liquid products, which are reduced in quantity, and secondly the unsaturated hydrocarbons formed are to some extent unstable. In practical application this means that the gases must be removed from the retort as quickly as possible, and that they must always travel towards the cooler end of the retort, or in the opposite direction to the material being treated, which must travel towards the hottest zone. The cool incoming material will always condense a certain amount of the outgoing gas, but this will be re-volatilised as the material approaches the hotter zone.

The removal of the gases is accelerated by passing some additional gas—*e.g.*, superheated steam, or producer gas through the retort, which sweeps along and carries out the evolving gases before serious decomposition can take place. If producer gas be used in this capacity, it is used at the same time to supply the heat for carbon-

isation, either wholly or in part. On account of the low specific heat of producer gas, a large volume must be passed through to impart the required quantity of heat to the material being retorted, and this involves large, and consequently expensive, condensers to cool the liquid products contained in so much gas. The producer gas of about 150 B.T.U. per cubic foot mixing with the rich low-temperature gas of 650 to 700 B.T.U. per cubic foot results in a gas of about 180 B.T.U. per cubic foot, which is too poor for the domestic appliances at present in vogue, and in consequence can only find a market for certain industrial purposes. On the other hand, the high calorific low-temperature gas would find a ready sale for enriching *water gas*, which is generally made at gas works. As water gas has a calorific value of only about 315 B.T.U. per cubic foot, it requires mixing with gases of higher calorific value before it can be supplied to the domestic consumer, whose appliances are designed for a gas of about 500 B.T.U. per cubic foot.

Although steam has a much higher specific heat than producer gas, its use as a heating medium for carbonisation, after being sufficiently highly superheated, presents many practical difficulties. Moreover, the latent heat—*i.e.*, the large amount of heat required to turn water into steam at the same temperature—must not only

be supplied in converting the water into steam, but must also be removed in the condensers after the steam has done its work. Practically the whole of this heat is lost, and on account of the low temperature at which steam condenses, it is probable that only a little of it could be recovered. Just as with producer gas, large condensers will be necessary, but more, because of the necessity, in the case of steam, of removing the latent heat of the steam.

Of these two mediums producer gas appears at present to be the more practicable for heating the charge in low-temperature carbonisation.

(3) Continuous Operation.

One of the most costly items in retorting is the supplying and getting rid of heat. It is, therefore, of the utmost importance both that the heat be applied in the most efficient manner possible, and that as much as possible of the waste heat from cooling the charge and the gases should do useful work. In a continuous process the temperature control is generally easier than in an intermittent process, and consequently wasteful application of heat is easier to avoid in the former type of retort. All designers aim at making their process as nearly as possible continuous, in order to benefit by both the thermal

gases will be cracked by contact with hot surfaces, whereas if it be heated too slowly the throughput of the retort will be unnecessarily low. Temperature control is one of three variables which for a given material determine the results to be obtained from a retort, the other two being rate of throughput, and rate at which heat may be imparted to the material. The last-named is to some extent a function of the size to which the material is broken. The heating of the retort must be capable of being regulated so that the rate of supply of heat to the retort is equivalent to the sum of:—

- (1) The rate of loss of heat by radiation.
- (2) The rate of heating required to raise the cold shale to the maximum retorting temperature.
- (3) The rate of extraction of heat from the retort in the spent shale and the evolved gases.
- (4) The work done.

It should, perhaps, be mentioned that this heat balance is practically rather than absolutely accurate, because no account is taken of stages in which material retorted may be *endothermic* (absorbing heat chemically) or *exothermic* (giving

out heat of its own accord), nor of the possible difference in heat capacity between the raw shale and that of the products retorted from it. The balance of in-put against out-put of heat will result in raising the temperature too high and decomposing and deteriorating the quality of the oils formed, whereas deficiency of in-put of heat will mean reduction of the amount of products obtained from the material being retorted.

It is generally easier to control the temperature of a liquid than of a solid, because unequal heat distribution in a liquid promotes circulation, and the hotter portion rapidly gives up its excess heat to the cooler portion, so keeping the whole of the liquid at the same temperature. This is one of the reasons why liquid heating mediums are favoured by some designers of retorts. If the substance to be retorted be crushed small, contact with a hot liquid allows the transference of heat from the liquid medium over the whole surface of each solid particle. This gives effective and rapid heating, and in a properly designed retort the gases evolved cannot to any extent come in contact with a higher temperature than that of the liquid, so that decomposition of the products is reduced to a minimum.

Temperature control must enable the material to be heated as quickly as possible, consistent

with the production of a good quality oil, and allow of the material passing through the retort as quickly as possible without either being overheated or failing to reach the full temperature required.

(5) Dust and Plastic Condition of Material.

Plasticity of oil shales, torbanites, etc., at temperatures below 600° C. connotes materials of high oil yield. The disadvantage of such rich substances, however, is that without some mechanism for keeping the material moving, whether in horizontal or vertical retorts, it will tend to cake on the retort walls, particularly in the former types. This will seriously hamper the working of the retort, and will necessitate shut-downs or partial shut-downs for cleaning, with the attendant loss of time and waste of heat. The mechanism in the retort may tend to form dust before and after the plastic stage, or to stir up existing dust, which may be carried over with the evolving vapours. If so, a dust extractor must be inserted, or some other means introduced of counteracting the mixing of the dust with the oil.

Mechanical devices for keeping the material moving forward must be such that the material cannot adhere and cake either on to the device

itself or on to the retort surface, and this condition is not fulfilled by simple screw conveyors running through the retort. The subject is dealt with in text-books on retorts.

In retorts with a *liquid-heating medium*, whether the particles of material being retorted are plastic or not makes no difference so long as there is sufficient liquid to prevent them from coalescing into one mass. Dust present in the liquid mixture cannot come over with the vapours except by some mechanical action such as priming. It has been proved that retorts with an internal liquid heating medium entirely overcome the difficulties due to both plasticity and dust.

Bituminous coals contain 1.3 to 1.6 per cent. of nitrogen, corresponding to 137 to 170 lbs. of ammonium sulphate per ton of coal, if the whole of the nitrogen be recovered in this form. Cannels and torbanites are very variable, containing from much less to much more nitrogen than the above figures. Esthonian oil shale contains from .29 to .48 per cent. nitrogen, corresponding to 30 and 50 lbs. of ammonium sulphate per ton. The maximum yield of this substance is obtained at about 900° C., but even at this temperature more than half the nitrogen remains in the coke. At the temperatures reached in low-temperature carbonisation, say about 600° C., only a little sulphate, about 15 lbs. per ton,

can be obtained from coal. The whole of the nitrogen can be recovered by heating coal to redness in a current of steam. This principle is applied in Scottish shale practice where, in the closing stages of retorting, the charge is submitted to a steam blast, and a recovery of 40 lbs. of ammonium sulphate per ton of shale is obtained, out of a theoretically possible 60 to 70 lbs. per ton.

In the near future, it is undoubtedly the richer shales, torbanites, etc., which will be first retorted, and it has been proved by various trials that, on account of the plastic stage through which these substances pass, they cannot be satisfactorily treated in Scottish retorts. One of the essential features of Scottish retorts, and, in fact, the feature to which in no small measure the industry in that country owes its survival, is the steaming for ammonium sulphate recovery. In low-temperature carbonisation, temperatures lower than those used in the hottest parts of Scottish retorts are likely to be general, and the extra cost and complication of providing for steaming and the additional heating may not be adequately compensated by the yield of ammonium sulphate to be derived.

In general, it may be said that on account of the low temperatures used in low-temperature carbonisation, the recovery of ammonium sulphate

can only be small, and will not make an appreciable contribution to the selling value of the products except with considerable expenditure for increased plant. Ammonium sulphate recovery must, therefore, be considered as applicable to low-temperature carbonisation in special circumstances only, and not as a general rule.

CHAPTER VII.

DISTILLATION PRODUCTS.

It is only intended here to give a very brief outline of the main products which are made available by low-temperature carbonisation. This system of carbonisation is specially designed to treat :—

- (1) Oil shales.
- (2) Cannel coals and torbanites.
- (3) Bituminous coals.
- (4) Lignites and brown coals.

The objects in view will be to obtain a preponderance of any one of or various combinations of the following :—

- (1) Gas.
- (2) Oil or tar.
- (3) Residue or semi-coke.

Gas manufacture as ordinarily practised for town or industrial purposes is not included in the above, as such supplies are obtained from

high-temperature carbonisation ($1,200^{\circ}$ C. to $1,400^{\circ}$ C.), but whatever the temperature, a certain amount of incondensable gas will be formed. One of the operating details of low-temperature carbonisation is to keep the formation of permanent gas at a minimum, as any excess gas will be formed at the expense of the oil.

In low-temperature carbonisation of bituminous coals, the object ordinarily will be to obtain the maximum possible amount of the best possible quality oil, together with a residue of semi-coke or smokeless fuel, containing 3 to 10 per cent. of volatile, capable of withstanding transport and suitable for burning in domestic grates. The high calorific value gas produced will find a ready sale at any average gas works for enrichment of water gas, which alone is of too low a calorific value for town supplies, and hence requires the addition of a gas of high calorific value. Alternatively, the gas may be consumed at the carbonisation plant for the production of heat and power. The removal of some 20 gallons of oil and 5,000 to 7,000 cubic feet of gas from the coal result in increasing the percentage of ash in the semi-coke as compared with that in the original coal. It is advantageous, therefore, to use *washed coals* or coals of low ash content, unless the semi-coke is to be applied to special

purposes, such as complete gasification in a producer. In the latter case a useful application is found for low-grade coals which cannot easily find a market, and are consequently at present wasted by being left in the mine or discharged on the tip heap.

The magnitude of the question of ash is brought home by figures given by Dr. Lessing in 1925—namely, that the transport of the mineral matter (ash) in coal in Great Britain amounts to 25 million tons in the year.

The *tars* produced from coals, whether from low-temperature carbonisation, gas retorts, coke ovens, producers, blast furnaces, or any other source, may be very roughly divided into two main portions, composed of hydrocarbons and tar acids respectively. A more satisfactory classification of the components of tars separates them into the following :—

- (1) Hydrocarbons, compounds of carbon and hydrogen.
- (2) Oxygenated compounds or tar acids, composed of carbon, hydrogen, and oxygen.
- (3) Nitrogen compounds containing carbon, hydrogen, and nitrogen, generally forming only a small proportion of the tar.

- (4) Sulphur compounds composed of carbon, hydrogen, and sulphur, or of two of these elements, and present in small quantities only.
- (5) Pitch and "free" carbon.

(1) Hydrocarbons.

The hydrocarbons in tars are the same as those which make up natural petroleum, but frequently in widely different proportions. They are divided as follows into various groups or series, each containing a number of different members which differ progressively both chemically and physically from one end of the series to the other. Of the total number of different members of the various series known to exist, only a small proportion is ordinarily found in petroleums or tars.

(a) The *paraffin* series of hydrocarbons, called "*saturated*," because they cannot take up any more hydrogen. The first four members are gases, the middle members liquids, with regularly increasing boiling points, and the higher members the solids of which paraffin wax is composed. Over 80 members of this series have been identified. This type of hydrocarbon characterises *Pennsylvanian*, *Galician*, and *Burmese* oils, and is obtained in considerable quantities from the oil retorted from Scottish shales.

(b) Hydrocarbons of the ethylene series, known as *olefines*, are termed “*unsaturated*,” because they readily combine with hydrogen to form additional products. In consequence of this, they are much less stable than the paraffins, and are acted on by relatively weak chemical reagents. Some 70 members of this series have been identified, which includes the gases ethylene and acetylene. Hydrocarbons of this series occur in practically all crude oils, but notably in those from *Burma*, and the carbonisation of all organic matter, including coal, gives rise to some members of the series.

(c) The *Naphthene*, or *hydro-aromatic*, series of saturated hydrocarbons has the same percentage composition as the olefines, but the internal arrangement of the molecules is different, and for this reason the series is known as isomers or polymers of the olefines. In consequence of this, with identical ultimate chemical composition, two *isomeric* substances may have entirely different chemical and physical properties. The naphthene hydrocarbons, being saturated, are very stable, and well over 100 members have been identified. *Russian* crude oils, and to some extent *Galician* oils, are characterised by the presence of these hydrocarbons.

(d) The *benzene* or aromatic series of unsaturated hydrocarbons are termed aromatic on account

of their characteristic odour. Though unsaturated, they are in this respect intermediate between the unsaturated olefines and the saturated naphthenes. This is due to the ring structure of the molecules, a subject dealt with in any text-book on the chemistry of oil. This series commences with the well-known substances, benzene, toluene, etc., or commercially benzol, and over 70 other members of the series are known. *Aromatics* are present in practically all crude petroleums, but they occur in notable quantities in the oils of *Borneo*, *Rumania*, and some of those of *Trinidad*. All crude petroleums are composed of some, or mixtures in some proportion, of the above four series of hydrocarbons.

(e) Other hydrocarbons are the *naphthalenes*, *anthracenes*, and *terpenes*, comprising about 100 different known members. These are associated more particularly with the high temperature distillation of coal, ordinary gas works tar containing a fair amount of the first two. Naphthalene does not occur in low-temperature tars, but its higher homologues are present. In natural petroleums the presence of naphthalene has occasionally been recorded in quantities which, though of considerable academic interest, are too small to be of practical significance.

(2) Oxygenated Compounds.

These *tar acids* or *phenols* are chemical derivatives of members of the aromatic hydrocarbon series. The phenols include phenol itself—i.e., *carbolic acid*, the *cresols*, and the *xilenols*. They are all readily soluble in caustic soda solution, and in this way may be separated from the hydrocarbons in tar. They may form up to 50 per cent. of low-temperature coal tar. They are strongly antiseptic, and are the main ingredient of disinfectants, such as *Lysol*, *Creoline*, etc., and also of disinfecting powders, insecticides, etc. They find numerous other uses, yielding by special treatment many medicines, dyes, explosives, and solid resinous products used for the manufacture of buttons, knife handles, insulators, and many other articles. Tar acids are also largely used as a preservative for creosoting timber.

On account of the very great number of valuable substances which can be obtained from the tar acids, as well as on account of their low calorific value, it is worth while, in ordinary circumstances, to separate them from the tar to be used as fuel.

(3) Nitrogen Compounds.

The nitrogen compounds are *ammonia*, *aniline*, *pyridine*, *quinoline*, and their homologues, and

other substances used as dyes, solvents, and for many other purposes. They rarely amount to more than 1 per cent. of low-temperature tars.

The ammonia, if recovered, is generally made into ammonium sulphate, which finds a ready market as a fertiliser.

Simmersback, retorting a Silesian coal at 600°C ., showed that 72 per cent. of the nitrogen remained in the coke, 18 per cent. came over as gas, 8 per cent. became ammonia, while 2 per cent. was contained in the tar. The nitrogen gas dilutes the permanent gas, but the amount of the former only increases to appreciable quantities at high temperatures. For example, if a coal contains 1.5 per cent. of nitrogen, the percentage of nitrogen in the gas from low-temperature carbonisation on the above figures will be 18 per cent. of this—*i.e.*, 0.27 per cent. of the coal; or a ton of coal yielding 5,000 cubic feet of gas of specific gravity .6 (air is 1), which weighs 230 lbs., will contain about 6 lbs. of nitrogen gas.

Crude petroleums contain small amounts of nitrogen, generally considerably less than 1 per cent.

At temperatures of carbonisation of 600°C . about 15 lbs. of ammonium sulphate per ton of coal would be available. Whether it would pay to install the additional plant necessary to obtain

this, or to install still further plant to increase this small amount, would require careful calculation in each particular case; no general rule can be laid down on this subject.

(4) Sulphur Compounds.

These are mostly compounds of *sulphur* with carbon or hydrogen or both. Their complete removal often forms one of the most difficult and expensive sections of refinery treatment of crude oils from whatever source, and the methods employed for eliminating them from tar oils are substantially those in use for natural petroleum.

The chief objection to sulphur and its compounds in oil is the extremely unpleasant odour which they impart on burning the oil. In the kerosene and petrol (gasoline) fractions the presence of 0.1 per cent. of sulphur compounds is sufficient to prevent their sale. The sulphur tends to accumulate in the heavier fractions, and consequently it is found in much greater proportion in the pitch than in the lighter oils.

In the earlier days of American petroleum development, prior to 1887, some oils were sold at about 15 per cent. of their real value at the time, because no method of eliminating the sulphur compounds had been perfected. Latterly,

the years 1919 to 1923 have witnessed the disappointment of hopes that the Kimmeridge shales of Dorset and Norfolk would supply a certain amount of oil. The oil can be obtained, but any chance it might have had of competing with free oil imported into Great Britain was destroyed by the difficulty and cost of removing the 6 to 8 per cent. or more of sulphur compounds which it contained. There seems every reason to expect that research will in time perfect the means of commercially overcoming this difficulty.

(5) Pitch and "Free" Carbon.

After distillation of the various fractions, pitch containing the *free carbon* remains in the still, or, if the distillation be carried to dryness, coke will remain. The free carbon is now considered to be mostly composed of heavy insoluble hydrocarbons rather than of carbon only. It is formed by the gases and liquids coming in contact with heated surfaces, and may be regarded as the final stage of cracking. This free carbon remains mixed with the pitch left in the still on completion of the fractionation of the tar, and the less the amount of contained free carbon, the greater the value of the pitch as a rule. Warnes, however, states that a certain amount of free carbon is necessary in a tar to ensure its being suitable

for treating road surfaces. The hardness of the pitch increases with rising still temperatures, as also does the carbon content. Pitch from gas tars produced at high temperatures may amount to over 60 per cent. of the tar, depending on the type of retort used, while in low-temperature tars it forms 30 to 40 per cent. of the tar. The "free" carbon may be 30 per cent. in the pitch from high-temperature tars, but may be absent, or at any rate should not exceed 3 per cent. in low-temperature tar pitch.

Dr. Franz Fischer states that a low-temperature tar from bituminous coal, produced at temperatures not exceeding 550° C., should have the following characteristics :—

- “(1) It should be fluid at room temperature, with possibly slight segregation of wax.
- “(2) Its specific gravity at 25° C. should be .95 to 1.06.
- “(3) In a thin layer it should be golden red or port wine colour.
- “(4) Freshly made, it generally smells of hydrogen sulphide or ammonium sulphide. It should never smell of *naphthalene*.”

He also emphasises the fact that naphthalene is

only formed from low-temperature tars in any quantity at temperatures of 750° C. and over. The presence of naphthalene, therefore, unless in minute traces only, is a sure proof that the tar has been greatly overheated.

The liquid products to be obtained by low-temperature carbonisation of bituminous coal depend primarily on the nature of the coal itself, and also to a great extent on the method of treatment, particularly as regards temperature and the length of time which the products of distillation remain in contact with the hotter parts of the retort or charge.

Of the various coal tar products enumerated above, bituminous coal retorted at a temperature not exceeding about 600° C. may be expected to yield a tar which will be made up of:—

Paraffin (saturated) hydrocarbons.

Olefine (unsaturated) hydrocarbons.

Naphthene (saturated) hydrocarbons.

Phenols or tar acids.

Nitrogenous substances.

The hydrocarbons will amount to 50 to 80 per cent. of the tar, and the phenols to 15 to 50 per cent. The nitrogenous compounds will not exceed 1 per cent. of the tar. Aromatic hydrocarbons (benzene series) will be present either in small

quantities only or not at all. They are considered to result from secondary actions which may take place as low as 500°C. , but which reach a maximum at about 800°C. , whereby some of the primary products are decomposed and form aromatics. For this reason they are characteristic of the high-temperature gas tars and coke-oven tars.

A low-temperature tar of the above nature in its hydrocarbon contents bears some resemblance to natural petroleums, particularly those characterised by naphthenes, such as *Russian* crude oils, but differs from them in other respects, especially in its content of phenols. It may be worked up into the following products:—

Motor spirit (including spirit from scrubbing gas), . . .	3 to 4 galls. per ton of coal.
Illuminating oil, . . .	1 to 3 " "
Gas oil, . . .	1 to 3 " "
Lubricating oils, . . .	0 to 2 " "
Paraffin wax (5 to 20 lbs.), . . .	$\frac{1}{2}$ to 2 " "
Pitch (40 to 60 lbs.), . . .	4 to 6 " "
Disinfectants, dyes, etc., . . .	3 to 8 " "

The loss on refining is high, and is unlikely to be less than 20 per cent. with present known methods. This is due partly to those *unsaturated* hydrocarbons which are unstable, and have to be eliminated or converted into *saturated* hydrocarbons with serious loss of oil and some loss of acid. If these unsaturated compounds be allowed

to remain, in course of time gummy deposits are found to separate out as the result of chemical alteration. These deposits are very likely to cause trouble in a motor car by sticking up the valves, etc., consequently the refinery treatment must ensure the removal of any hydrocarbons which give rise to them.

It is, of course, only necessary to remove those unsaturates which form gummy or resinic deposits, the unsaturates which do not do so being quite suitable for motor fuel. Unsaturated and aromatic hydrocarbons are undesirable in illuminating oils, because they tend to cause lamps to burn with a smoky flame.

The efficiency of an internal combustion engine depends to a great extent on its *compression ratio*, and up to a point the higher the compression ratio the greater the efficiency of the engine. With average motor spirit, however, until recently a compression ratio greater than 5 to 1 was found to cause generally *detonation*—i.e., violent explosion of the charge. The prevention of this detonation, and the production of a fuel which would not cause it, has been the object of motor car designers and fuel technologists for some time now, and knowledge of the subject has been enormously advanced. While the shape of the combustion chamber, ports, etc., of an engine influence its tendency to

detonate, the composition of the fuel is the most important factor. For instance, an average motor car engine run on benzene series hydrocarbons, commercially called benzol, will not detonate, and the presence of a small amount of these hydrocarbons in a fuel, even if it does not always entirely prevent the fuel from detonating, will greatly reduce its tendency to do so.

Oil companies are endeavouring to be in a position to supply anti-knock motor car fuels, because they know that once high compression motor car engines are supplied to the public, the demand for them will increase at a tremendous rate, and those who can supply anti-knock fuel for that class of engine will naturally get the orders.

Of the products mentioned, lubricating oil is the most difficult to manufacture. In Germany it is made in fairly large quantities from brown coal tar, but the process of manufacture does not yet seem to have been perfected to the point where the lubricants marketed are quite as good as those from natural petroleum.

Towards the end of 1924 the *Fuel Research Board* made a test of the *Parker Plant* at Barnsley, England. This is a low-temperature carbonisation plant for obtaining oils and smokeless domestic fuel from bituminous coal. The amount of coal used in the test was $91\frac{1}{2}$ tons, and its volatile

combustible content was 36 per cent. The products per ton of coal were :—

Crude tar,	18.62 gallons (British) of specific gravity 1.063.
Tar acids,	3.18 gallons.
Gas,	5,620 cubic feet of calorific value 704 B.T.U. per cubic foot after being washed.
Coke,	Probably 14 cwts.

Fractionating the tar to 170° C. gave 1.09 gallons of spirit, and a further 1.78 gallons were obtained by scrubbing the gas, which added gives a total of 2.87 gallons of crude motor spirit per ton. This crude spirit gave 2.16 gallons of refined motor spirit per ton. The refining of the tar showed a pitch content of 48 per cent. The coke was in 1-inch to 3-inch pieces, and contained only 4.6 per cent. of breeze. The temperature was higher than it should have been, having reached a maximum of 800° C. This must have had a slightly unfavourable effect on the liquid products.

One of the difficulties encountered in processes of this nature, particularly those which, unlike the Parker, do not leave the charge stationary during carbonisation, has been the *friable* nature of the resulting semi-coke and the quantity of dust or fines formed, sometimes amounting to half the coke. The production of a semi-coke or smokeless fuel which will stand transport to

the domestic industrial consumer is a necessary condition for the success of these processes, except in cases where they can supply a demand for pulverised fuel, for which this semi-coke is very suitable.

The use of *pulverised* fuel under boilers is making rapid headway, especially in America. It is based on the idea that if a suitable fuel be burnt in a very finely divided state, conditions of combustion will approximate to those of gas firing. This gives the highest efficiency, because the amount of air supplied may be reduced almost to the theoretical quantity necessary, hence heat is not wasted in raising the temperature of surplus air and increasing the losses in the flue gases. Pulverised fuel is fed through pipes, and ease of control is almost comparable with that of oil firing. Extensive use of pulverised fuel would undoubtedly lead to the necessity of preventing large quantities of dust being discharged into the atmosphere of towns, but this is easily accomplished by special appliances.

In the old-established *Scottish* oil shale industry a complete range of products is manufactured, but, of course, unlike the case of carbonising coal, the residue is non-combustible and useless. The retorts are vertical, and are made of an upper steel section and a lower firebrick section. The charge enters at the top, where most of the

distillation of the oils takes place, while in the lower section it is raised to a much higher temperature and steamed for the purpose of ammonium sulphate recovery. Although the crude oil obtained is not more than about 22 gallons per ton of shale, it is of very good quality, and yields, besides the usual motor spirit, lamp oil, paraffin wax, etc., excellent lubricating oils. In addition to the oils and wax, about 40 lbs. of ammonium sulphate is obtained per ton of shale.

At *Autun*, in France, likewise, a complete range of products, including sulphate of ammonia, is manufactured from the shale and torbanite there, but the yield of crude oil is only 15 to 18 British gallons per metric ton of shale. The amount of material retorted in 1924 was 67,000 metric tons.

The refining of petroleum is a highly technical branch of chemical engineering, and is now in such a remarkable state of advancement that from a given crude oil large or small amounts of certain classes of products may be obtained at will by varying the methods of treatment of the oil. This is largely due to the development of processes known as "*cracking*." Cracking is heat treatment of an oil, under special conditions, with the object of breaking down the molecular structure, with the result of forming a larger quantity of lighter oil together with

carbon and gas. For instance, by cracking 3 gallons of kerosene, approximately 2 gallons of petrol (gasoline) may be obtained. In the United States in the last twenty years the average yield of motor spirit from crude petroleum has trebled itself. This is due partly to using higher boiling and heavier spirits, but mainly to the increasing use of cracking processes.

Refining losses and difficulties are in a measure due to the formation of unstable unsaturates, and, as these compounds are formed to a much greater extent in low-temperature tars than in torbanite oils, the latter are both easier to refine and the loss on refining is less. The oils from cannel coals occupy an intermediate position in this respect. Straight run or uncracked motor spirit from natural petroleum is practically free from these unstable compounds, and the losses in refining are small, but cracked motor spirit from natural petroleum contains them and requires their removal with considerable losses, just as in the case of spirit from low-temperature tar, etc. Shale oils in general may be expected to contain a relatively large amount of unsaturated hydrocarbons, so that with present methods refining losses are high.

In the case of low-temperature coal tar, refining methods are not standardised in the sense that they are for petroleum, but the principles

are similar, and practice will, no doubt, evolve on lines embodying a combination of petroleum, shale oil, and high-temperature tar-refining methods. It is well known that all the essential types of liquid fuels and lubricants at present almost universally supplied by natural petroleum can be obtained from coals, shales, torbanites, etc., and, in addition, many other valuable products are manufactured. Moreover, that they can in certain circumstances be produced at a cost which enables them to compete with petroleum products is proved by the existence of commercial retorting undertakings in various parts of the world.

In Chapter V. mention has been made of *Bergius'* process for hydrogenating and liquifying coal and heavy oils under very high pressures. Marketable products are obtained, but the plant is somewhat expensive, and the possibility of extended application of the process appears to depend mainly on the cost of plant.

A fuel called "*Tetralin*" is manufactured in Germany. Chemically pure naphthalene is put into vessels with agitators and a nickel-copper catalyst, and the pressure is raised to 600 lbs. per square inch, and the temperature to over 150° C. Hydrogen is then injected into the naphthalene, and converts it into tetrahydronaphthalene, termed, for short, tetralin. It is

a liquid of .925 specific gravity, boiling point 206° C., and flash point 79° C. It is suitable for Diesel engine fuel, and, if not more than 50 per cent. tetralin be mixed with petrol, benzol, etc., it may be used in motor cars, and is almost as good as the usual motor car fuels. At present about 40,000 tons (260,000 barrels) of tetralin per year are made. The supplies of naphthalene available will determine the limit to the possible increase of output.

Another fuel called "*synthol*" has been made on a small scale in Germany. Coke or semi-coke in a producer is completely converted into water gas, which is a mixture of carbon monoxide and hydrogen in almost equal volumes. The water gas is then subjected to *hydrogenation* under high pressure and temperature in the presence of a catalyst, and liquid products are obtained. This method appears to have considerable possibilities.

There does not appear to be any immediate prospect of *alcohol* as a fuel augmenting world supplies to any great extent; at the same time, the possible amounts of this fuel which could be made are inexhaustible, so that the subject cannot be passed over without mention.

Alcohol may be made from almost any vegetable substance, but in most cases either the yield is low, or the expense of treatment is high.

Potatoes yield 20 gallons and sugar beet 21 gallons of '95 per cent. alcohol per ton. Various tropical plants or vegetables, such as cassava, sweet potato, and maize give similar yields. Molasses, a by-product from the manufacture of sugar, is in some cases run to waste. It gives 69 gallons of alcohol per ton, and is the most hopeful potential source of supply, but its limitation is the fact that the whole of the world's molasses could not give much more than 250 million gallons of alcohol per year.

In South Africa a motor car fuel called "*Natalite*" is made. It is composed of alcohol made from molasses and mixed with ether.

One of the factors which at present appears to prevent the possibility of cheap alcohol is the very large amount of raw material which must be handled to produce a small amount of the finished product. There are also various chemical problems to be solved before the cheapest vegetable materials, such as waste vegetation, in the tropics, could be treated at a reasonable cost.

Alcohol, except in special circumstances, must be regarded as a future reserve of fuel, but one of which the possible supply will be almost unlimited.

In the following table are set out for comparison some of the commercial fractions which may be obtained from petroleums, shales, coals, and torbanites :—

TABLE VIII.—COMPARING THE MARKETABLE PRODUCTS FROM PETROLEUM, OIL SHALE, TORBANITE, ETC.

	Crude Oil.	Motor Spirit —200° C.	Kerosene 200-275° C.	Fuel.	Phenolic Compounds.	Crude Sp. Gr.
David T. Day,	Pennsylvania, Texas.	Per cent. 24.4	Per cent. 16.4	Per cent. 59.2	Per cent. None	.833
	Oklahoma.	1.4	40.0	58.6	None	.843
	Heavy Mexican.	12.0	35.0	53.0	None	.864
	Light Mexican.	2.9	5.9	91.2	None	.979
	California.	4.4	16.0	79.6	None	.933
Fischer,	Low temperature tar from gas coal.	6.9	32.7	60.4	None	.921
	Low temperature tar from bituminous coal.	10.0	*12.5	26.0	34.0	about 1
D. E. Winchester, p. 131, <i>Petroleum World</i> , Jan. 1924,	Oil from Green River shale, Wyoming.	6.1	*25.5	21.4	11.5	*
	Oil from South African torbanite from Utrecht.	22.5	17.0	60.5	None	.933
R. H. Cambage, Royal Society, N.S. Wales, 16th June, 1924.	Oil from New South Wales torbanite at Capertee.	28.0	*30.0	42.0	None	*.88
	Scottish shale.	5.0 1.83	20.0 22.518	50.0 ?	None ?	Tempera- tures not stated. .875

* To 300° C.

The greatest number of gallons of oil per ton of material retorted is obtained from the torbanites, which occur in association with coal in many parts of the world, and the type of oil yielded is one which refines easily, without excessive loss, and gives products of excellent quality. In spite of the great richness of these materials, torbanites have only been worked on a large scale at *James Young's* works at Bathgate, in Scotland, from 1850 to 1862, in which year the supply was exhausted, probably to some extent in the United States till 1860, and more recently at *Newnes*, in New South Wales, and at *Autun*, in France. At both Bathgate and Newnes yields of over 100 British gallons of oil per ton of torbanite were obtained on a commercial scale.

Next in magnitude of yield are the torbanitic cannel and the rich oil shales which will in many cases give 50 to 80 British gallons of crude oil per ton.

Smaller yields of oil are obtained from coals, lignites, and the leaner shales. The shales at present being worked in Scotland give about 22 gallons of oil per ton.

To obtain the best results from fuels in any particular country is a problem of great complexity, as the solution involves innumerable side issues, many of which are themselves of vital importance. If the object be to produce oil

only, then the torbanites, cannels, and richer shales must be retorted. When the raw materials are themselves not sufficiently rich to allow of their being retorted for oil, they can only be utilised if they can be worked in conjunction with some other operation, such as coal mining. Whatever the material, there are always limiting conditions, which mean that when the material reaches a certain degree of poorness, it cannot be worked at a profit. For this reason, waste of material appears inevitable, and only by utilising or treating the different types of raw material in the way which makes them most valuable can this waste be reduced to the minimum.

CHAPTER VIII.

FUTURE LIQUID FUEL SUPPLIES.

IT must be abundantly evident from the facts already mentioned that any serious *shortage* of liquid fuel within the next few centuries may safely be regarded as a somewhat remote possibility. On the other hand, it is hardly conceivable that petroleum from wells can continue to be the chief source of liquid fuels for more than a few decades, but the knowledge of the vastness and the certainty of the oil available from oil shales, cannels, and torbanites allows us to contemplate the inevitable decadence of present sources of petroleum with equanimity. In addition, the known and measured coal reserves of the world will, by processes which have been proved practicable, provide ample oil to banish the spectre of a possible shortage many centuries further away. Finally, there is practically no limit to the amount of alcohol which may be produced when economic conditions allow of it. In the many centuries which must elapse before the exhaustion of the world's coal and shale

reserves, it seems quite reasonable to assume that the advance of science will make available to industry solar, tidal, radio-active, or other forms of energy, so that we need have no concern except for the immediate future. In these circumstances, it may be reiterated that there will not be, that there cannot be, a really serious and prolonged shortage of liquid fuels in the near future.

Although the sources of supply of liquid fuels for centuries ahead are proved and in sight, it is equally indisputable that present sources must be gradually and increasingly supplemented from the reserves mentioned if temporary stringency is to be entirely avoided. No one attempts to deny the basic fact that oil fields, known and unknown, contain in each case a definite amount of oil, and once that oil has been removed it has gone for good, and is not replaced, except in so far as redistribution or flow from adjacent rocks may re-introduce a certain amount of pre-existing oil into the depleted zone. Increasing supplies of petroleum under present conditions will be obtained by :—

- (1) The discovery of new oil fields.
- (2) Deeper and more rapid drilling in both old and new fields.
- (3) Leaving less oil behind in the rocks from which production is obtained.

Since no one of these factors can be extended indefinitely, it follows that the increase of supplies of oil from present sources cannot be expanded indefinitely. There is a limit to the ultimate amount of petroleum which can be won, and consequently there must come a time when world production from wells will cease to increase. There are likely to be oscillations when this phase is reached, some years recording a decrease and some years an increase in accordance with economic conditions, and the advances made in production methods, but each year rapidly leading nearer to the inevitable decline. The question which is so much exercising those responsible for supplying petroleum is whether this phase has already commenced. Opinion is divided, but in the United States, which is by far the largest petroleum producing and consuming country in the world, there is undoubtedly a widely prevalent expectation that supplies from outside the country must now be increasingly relied on to satisfy the internal demand.

The immediate future of oil development is a matter which will be largely dependant on certain economic factors over which effective control cannot be exercised. Any considerable rise in price would at once set in motion changes which would have a far-reaching effect on the oil industry. The first of these would be a prompt

curtailment of demand and the rapid acceleration of the development of the high compression motor car engine. This would force the much more general adoption of what is already obtainable—namely, anti-detonating or *anti-knock* motor car fuels. In a car the high compression engine with a suitable fuel will result in at least 25 per cent. more mileage for a given fuel consumption. Increased prices would lead to increased drilling activities, and to carrying these activities into places which are at present considered too inaccessible to be profitably developed. Finally, unless the rise of price had the appearance of being purely transient, it would give the impetus required to start a number of oil-shale retorting processes which have passed the experimental stage, but which have not yet attained large-scale commercial production.

Provided that research workers are ahead of commercial achievements, as they certainly are at present, and that they will be ready for the rapid development of new processes when required, it would appear that the price of oil alone will be sufficient to ensure to a greater or less extent, the installation of retorting plants when they become necessary. The weakness of this comfortable supposition lies in the fact that the amount of plant required to make any appreciable addition to the present output of

oil must be on a vast scale. It will take years to install and perfect sufficient plant to supply from oil shales even 10 per cent. of the world's oil requirements, consequently it is of the greatest importance that every effort should be made to commence at once the supply of oil from oil shales, cannels, etc., wherever there may be a chance of success.

In Chapter V. some brief indication has been given as to the types and amounts of some of the reserves of retortable materials in the world. It has also been shown that the liquid products derived from these materials are in every way suitable to supplement or replace supplies of petroleum products. The amazing rate of increase in the use of liquid fuels and the uncertainty as to how long natural petroleum may be able to supply the world's requirements without difficulty, make it doubly desirable that no opportunities of establishing additional sources of supply should be lost. The first opportunities occur in those countries which have reserves of rich retortable material but little or no indigenous natural petroleum, and where liquid fuel requirements have to be met by importation from foreign countries.

The *Scottish oil-shale* industry has been operating continuously for 75 years, though unfortunately at the present time the decreasing

more and more from sources capable of virtually unlimited expansion, and less and less from oil-fields which, although they have hitherto proved capable of meeting unprecedented increases in demand, are at best an unknown and uncertain quantity so far as the future is concerned.

GLOSSARY.

Absorbed. Liquids which have been sucked in by solids, and which can be removed from them by solvents, are said to be *absorbed* by the solids.

Adsorbed. Liquids which adhere to the surface of solids, resulting in a relatively high concentration of the solution at the place of contact, and which can be driven off by heat, are said to be *adsorbed* by the solid.

Algæ, low types of plants, such as seaweeds.

Bituminous Coals, coals of fairly high volatile content which burn with a smoky flame; they may be caking or non-caking, and they contain no bitumen.

British Thermal Unit (B.T.U.), the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit.

Caking Coals, coals which on heating become semi-fused and coalesce with considerable expansion.

Calorie, the heat required to raise the temperature of one Kilogramme of water one degree Centigrade. 1 calorie = 3.968 B.T.U.

Calorific Value, the amount of heat, usually expressed as B.T.U. or as Calories, which unit weight or unit volume of a substance can give out on combustion.

Catalysts, substances which promote or intensify chemical action between other substances without themselves entering directly into the reactions.

Cracking, chemical decomposition of an oil to obtain a lighter oil. It is brought about by introducing it into a hot chamber, where it is broken up by heat into a lighter oil than the one introduced, carbon residue and gas.

Fractionating a liquid is heating it in a closed vessel and collecting and condensing the vapours which come off as the temperature is raised.

Gels, stable colloidal aggregations.

Homologues. A series of different compounds formed by different combinations of the same elements, in which the increase of the elements is proportional, is said to be a homologous series. Any one member is a homologue of any other of the series.

Jetonised, a stage in coalification intermediate between vegetable matter and true coal.

Kerogen, (1) the combustible matter in oil shales ;

(2) that part of the combustible matter of cannel or torbanites which is not jetonised or coal material.

Manjak, Albertite, etc., are hard glistening splintery forms of pitch or bitumen.

Shale, a homogeneous rock of compacted fine grained detrital material.

Specific Gravity, the weight of a substance as compared with the weight of an equal volume of water.

Specific Heat, the amount of heat required to raise a given quantity of a substance one degree ; conversely, it is the amount of heat given out by the same substance when its temperature falls the same amount.

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